518 Rec'd PCT/PTO 08 AUG 2001

FORM PTO-1390 (REV 10-94) U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE		ATTORNEY'S DOCKET NUMBER
TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371		10873.779USWO
		U S APPLICATION NO (If known, see 37 C F R 1 5) to be assigned 09/913018
INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/JP00/00728	February 9, 2000	February 10, 1999

TITLE OF INVENTION

REFLECTIVE OPTICAL DEVICE, AND REFLECTIVE SOLID-STATE OPTICAL DEVICE, AND IMAGING DEVICE, MULTI-WAVELENGTH IMAGING DEVICE, VIDEO CAMERA DEVICE, AND VEHICLE-MOUNTED MONITOR UTILIZING THE SAME

APPLICANT(S) FOR DO/EO/US

Motonobu YOSHIKAWA; Yoshiharu YAMAMOTO

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [X] This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. [ ] This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. [X] This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(l).
4. [X] A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. [X] is transmitted herewith (required only if not transmitted by the International Bureau).
   b. [X] has been transmitted by the International Bureau.
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US)
6. [X] A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. [X] Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. [ ] are transmitted herewith (required only if not transmitted by the International Bureau).
   b. [ ] have been transmitted by the International Bureau.
   c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   d. [X] have not been made and will not be made.
8. [ ] A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. [X] An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
10. [X] A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern document(s) or information included:

11. [ ] An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. [X] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. [X] A FIRST preliminary amendment.
    [ ] A SECOND of SUBSEQUENT preliminary amendment.
14. [ ] A substitute specification.
15. [ ] A change of power of attorney and/or address letter.
16. [X] Other items or information: Marked-up version showing changes made, International Search Report, PCT Request, Written Reply, Written amendments, form PCT/IB/301, form PCT/IB/304, for PCT/IB/308, form PCT/IPEA/401, form PCT/IPEA/409 in Japanese, form PCT/IB/332

Adjustment date: 10/12/2001 THOLLAND
08/14/2001 MKAYPAGH 00000051 09913018
10/12/2001 THOLLAND 00000003 09913018
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518 Rec'd PCT/PTO 08 AUG 2001

U.S. APPLICATION NO (If known, see 37 C F R 1 5)	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
to be assigned 09/913018	PCT/JP00/00728	10873.779USWO

17. [X] The following fees are submitted: — CALCULATIONS — PTO USE ONLY

BASIC NATIONAL FEE (37 CFR 1.492(a) (1)-(5)):

Search Report has been prepared by the EPO or JPO....................$860.00

International preliminary examination fee paid to USPTO (37 CFR 1.492(a)(1))....................$690.00

No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2))....................$710.00

Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(3)) paid to USPTO.................... $1000.00

International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4)....................$100.00

				CALCULATIONS	PTO USE ONLY
ENTER APPROPRIATE BASIC FEE AMOUNT =				$860.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(e)).				$0.00	
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	108 -20 =	88	X $18.00	$1584.00	
Independent claims	7 -3 =	4	X $80.00	$320.00	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ $260.00	$0.00	
TOTAL OF ABOVE CALCULATIONS =				$2764.00	
Reduction by 1/2 for filing by small entity, if applicable. Small entity status is claimed pursuant to 37 CFR 1.27				$0.00	
SUBTOTAL =				$2764.00	
Processing fee of **$130.00** for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f). +				$0.00	
TOTAL NATIONAL FEE =				$2764.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). $40.00 per property +				$40.00	
TOTAL FEES ENCLOSED =				$2804.00	
				Amount to be: refunded	$0.00
				charged	$0.00

a. [X] Check(s) in the amount of $2764.00 for filing fee and $40.00 for assignment recordation to cover the above fees is enclosed.

b. [ ] Please charge my Deposit Account No. ________________ in the amount of $ ____________ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. [X] The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 13-2725.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO
Douglas P. Mueller
MERCHANT & GOULD
P.O. Box 2903
Minneapolis, MN 55402-0903

SIGNATURE: [signature]

NAME: Douglas P. Mueller

REGISTRATION NUMBER: 30,300

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

09/913018

Applicant: Yoshikawa et al.

Docket: 10873.779USWO

Title: REFLECTIVE OPTICAL DEVICE, AND REFLECTIVE SOLID-STATE OPTICAL DEVICE, AND IMAGING DEVICE, MULTI-WAVELENGTH IMAGING DEVICE, VIDEO CAMERA DEVICE, AND VEHICLE-MOUNTED MONITOR UTILIZING THE SAME

CERTIFICATE UNDER 37 CFR 1.10
'Express Mail' mailing label number. EL669945125US
Date of Deposit: August 8, 2001
I hereby certify that this paper or fee is being deposited with the United States Postal Service 'Express Mail Post Office To Addressee' service under 37 CFR 1.10 and is addressed to the Commissioner for Patents, Washington, D.C. 20231.
By: Omesh Singh
Name: Omesh Singh

BOX PCT
Commissioner for Patents
Washington, D.C. 20231

Sir:

We are transmitting herewith the attached:

- ☒ Transmittal sheet, in duplicate, containing Certificate under 37 CFR 1.10.
- ☒ National Stage PCT Patent Application: Spec. 59 pgs; 108 claims; Abstract 1 pgs. The fee has been calculated as shown below in the 'Claims as Filed' table.
- ☒ 40 sheets of formal drawings
- ☒ A signed Combined Declaration and Power of Attorney
- ☒ Assignment of the invention to Matsushita Electric Industrial Co., Ltd., Recordation Form Cover Sheet
- ☒ A check in the amount of $2764.00 to cover the Filing Fee
- ☒ A check for $40.00 to cover the Assignment Recording Fee.
- ☒ Other: Preliminary Amendment, form PTO-1390, copy of pct application, Marked-up version showing changes made, International Search Report, PCT Request, Written Reply, Written amendments, form PCT/IB/301, form PCT/IB/304, for PCT/IB/308, form PCT/IPEA/401, form PCT/IPEA/409 in Japanese, form PCT/IB/332
- ☒ Return postcard

CLAIMS AS FILED

Number of Claims Filed		In Excess of:		Number Extra		Rate		Fee
Basic Filing Fee								$860.00
Total Claims								
108	-	20	=	88	x	18.00	=	$1584.00
Independent Claims								
7	-	3	=	4	x	80.00	=	$320.00
MULTIPLE DEPENDENT CLAIM FEE								$0.00
TOTAL FILING FEE								$2764.00

Please charge any additional fees or credit overpayment to Deposit Account No. 13-2725. A duplicate of this sheet is enclosed.

MERCHANT & GOULD P.C.
P.O. Box 2903, Minneapolis, MN 55402-0903
(612) 332-5300

By:
Name: Douglas P. Mueller
Reg. No.: 30,300
Initials: DPMueller/jlc

23552
PATENT TRADEMARK OFFICE

(PTO TRANSMITTAL - NEW FILING)

S/N unknown

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant:	Yoshikawa et al.	Docket No.:	10873.779USWO
Serial No.:	unknown	Filed:	concurrent herewith
Int'l Appln No.:	PCT/JP00/00728	Int'l Filing Date:	February 9, 2000
Title:	REFLECTIVE OPTICAL DEVICE, AND REFLECTIVE SOLID-STATE OPTICAL DEVICE, AND IMAGING DEVICE, MULTI-WAVELENGTH IMAGING DEVICE, VIDEO CAMERA DEVICE, AND VEHICLE-MOUNTED MONITOR UTILIZING THE SAME		

CERTIFICATE UNDER 37 CFR 1.10
'Express Mail' mailing label number: EL669945125US
Date of Deposit: August 8, 2001
I hereby certify that this correspondence is being deposited with the United States Postal Service 'Express Mail Post Office To Addressee' service under 37 CFR 1.10 on the date indicated above and is addressed to the Assistant Commissioner for Patents, Washington, D.C . 20231.

By: Omesh Singh
Name: Omesh Singh

PRELIMINARY AMENDMENT

Box PCT
Assistant Commissioner for Patents
Washington, D. C. 20231

Dear Sir:

In connection with the above-identified application filed herewith, please enter the following preliminary amendment, which is based on the Article 34 amendments, a copy of which is enclosed herewith:

IN THE ABSTRACT

Insert the attached Abstract page into the application as the last page thereof.

IN THE SPECIFICATION

A courtesy copy of the present specification is enclosed herewith. However, the World Intellectual Property Office (WIPO) copy should be relied upon if it is already in the U.S. Patent Office.

Please replace the paragraph beginning at page 42, line 21, with the following rewritten paragraph:

-- FIG. 18 is a view illustrating a configuration of a multi-wavelength imaging device according to a fourth embodiment of the present invention. Reference numerals 11 to 13 denote the same members as those in the third embodiment. In the fourth embodiment, the device further includes a wavelength selecting filter 15, an infrared imaging element 16, and a visible imaging element 17. The wavelength selecting filter 15 transmits only infrared rays (wavelength: 3μm to 5μm, or 8μm to 12μm) and reflects visible rays (wavelength: 400nm to 750nm). The infrared imaging element 16 has sensitivity with respect to infrared rays, while the visible imaging element 17 has sensitivity with respect to visible rays.--

Please replace the paragraph beginning at page 49, line 28, with the following rewritten paragraph:

-- FIG. 29 illustrates an example in which an imaging device 40 according to the present invention is mounted on a vehicle 41, so as to be used as a vehicle-mounted monitor including a vehicle-mounted visual supporting device. A situation ahead of a vehicle 41 is imaged by an imaging device 40. By processing the image, it is possible to detect whether or not the vehicle is deviating from a traffic lane. Besides, by displaying the image on a display device (not shown) provided at a driving seat, it is possible to support human vision.--

IN THE CLAIMS

Please amend the claims as follows:

16. (amended) The reflective optical device according to claim 11, wherein the at least three reflection surfaces are non-axisymmetric surfaces.

17. (amended) The reflective optical device according to claim 11, wherein the reflection surfaces are four surfaces that are a first surface, a second surface, a third surface, and a fourth surface in an order from the object side in a direction in which the light fluxes travel.

32. (amended) An imaging device, comprising:

the reflective optical device according to claim 1; and

a detecting means that converts a light intensity into an electric signal.

37. (amended) The multi-wavelength imaging device according to claim 35, wherein the reflective optical device is the reflective optical device comprising two non-axisymmetric reflection surfaces for bringing light fluxes from an object into focus on an image surface, the two non-axisymmetric reflection surfaces being a first reflection surface and a second reflection surface, wherein:

the first and second reflection surfaces are disposed in this order in a direction in which the light fluxes travel, and are arranged eccentrically; and

each of the first and second reflection surfaces is concave in a cross-sectional shape taken along a plane containing a center of the image surface and vertices of the reflection surfaces.

40. (amended) The multi-wavelength imaging device according to claim 39, wherein the reflective optical device is the reflective optical device comprising two non-

axisymmetric reflection surfaces for bringing light fluxes from an object into focus on an image surface, the two non-axisymmetric reflection surfaces being a first reflection surface and a second reflection surface, wherein:

the first and second reflection surfaces are disposed in this order in a direction in which the light fluxes travel, and are arranged eccentrically; and

each of the first and second reflection surfaces is concave in a cross-sectional shape taken along a plane containing a center of the image surface and vertices of the reflection surfaces.

42. (amended) A vehicle-mounted monitor, comprising:

a multi-wavelength imaging device according to claim 35; and

a display means that conveys an obtained image to a driver.

83. (amended) An imaging device, comprising the reflective optical device according to claim 43, wherein an imaging element is provided at a portion of the reflective optical device where an image is formed.

85. (amended) An imaging device, comprising the reflective optical device according claim 43, wherein an imaging element having sensitivity to a visible range is provided at a portion of the reflective optical device where an image is formed.

86. (amended) An imaging device, comprising the reflective optical device according to claim 43, wherein an imaging element having sensitivity to a visible range and an infrared range is provided at a portion of the reflective optical device where an image is formed.

87. (amended) An imaging device, comprising the reflective optical device according to claim 67, wherein an imaging element having sensitivity to a visible range and an infrared range is provided at a portion of the reflective optical device where an image is formed.

88. (amended) An imaging device, comprising the reflective solid-state optical device according claim 77, wherein an imaging element is provided at a portion of the reflective solid-state optical device where an image is formed.

90. (amended) An imaging device, comprising the reflective solid-state optical device according to claim 81, wherein an imaging element having sensitivity to a visible range and an infrared range is provided at a portion of the reflective solid-state optical device where an image is formed.

Please add the following new claims:

95 ~~96~~. (new) The reflective optical device according to claim 12, wherein the at least three reflection surfaces are non-axisymmetric surfaces.

96 ~~97~~. (new) The reflective optical device according to claim 15, wherein the at least three reflection surfaces are non-axisymmetric surfaces.

97 ~~98~~. (new) The reflective optical device according to claim 12, wherein the reflection surfaces are four surfaces that are a first surface, a second surface, a third surface, and a fourth surface in an order from the object side in a direction in which the light fluxes travel.

98 ~~99~~. (new) The reflective optical device according to claim 15, wherein the reflection surfaces are four surfaces that are a first surface, a second surface, a third surface, and a fourth surface in an order from the object side in a direction in which the light fluxes travel.

99 ~~100~~. (new) An imaging device, comprising:

the reflective optical device according to claim 11; and

a detecting means that converts a light intensity into an electric signal.

100 ~~101~~. (new) An imaging device, comprising:

the reflective optical device according to claim 12; and

a detecting means that converts a light intensity into an electric signal.

101 ~~102~~. (new) An imaging device, comprising:

the reflective optical device according to claim 15; and

a detecting means that converts a light intensity into an electric signal.

102 ~~103~~. (new) The multi-wavelength imaging device according to claim 35, wherein the reflective optical device comprising at least three reflection surfaces for bringing light fluxes from an object into focus on an image surface, wherein:

the reflection surfaces are arranged eccentrically;

an F value in a plane containing vertices of the respective reflection surfaces is less than 3.5; and

among the reflection surfaces, the two reflection surfaces on the object side are given as a first reflection surface and a second reflection surface, respectively, in an order from the object side in a direction in which the light fluxes travel, and each of the first and second reflection surfaces is concave in a cross-sectional shape taken along the plane.

103 ~~104~~. (new) The multi-wavelength imaging device according to claim 35, wherein the reflective optical device comprising at least three reflection surfaces for bringing light fluxes from an object into focus on an image surface, wherein:

the reflection surfaces are arranged eccentrically; and

an F value in a plane containing vertices of the respective reflection surfaces is less than 1.9.

104 ~~105~~. (new) The multi-wavelength imaging device according to claim 35, wherein the reflective optical device comprising at least three reflection surfaces for bringing light fluxes from an object into focus on an image surface, wherein:

the reflection surfaces are arranged eccentrically;

among the reflection surfaces, the reflection surface placed second from the object side in a direction in which the light fluxes travel is given as a second reflection surface, and the second reflection surface is concave in a cross-sectional shape taken in the vicinity of its vertex along a plane containing vertices of the reflection surfaces, and is convex in a cross-sectional shape taken in a direction perpendicular to the plane.

105 ~~106~~. (new) The multi-wavelength imaging device according to claim 39, wherein the reflective optical device comprising at least three reflection surfaces for bringing light fluxes from an object into focus on an image surface, wherein:

the reflection surfaces are arranged eccentrically;

an F value in a plane containing vertices of the respective reflection surfaces is less than 3.5; and

among the reflection surfaces, the two reflection surfaces on the object side are given as a first reflection surface and a second reflection surface, respectively, in an order from the object side in a direction in which the light fluxes travel, and each of the first and second reflection surfaces is concave in a cross-sectional shape taken along the plane.

106 ~~107~~. (new) The multi-wavelength imaging device according to claim 39, wherein the reflective optical device comprising at least three reflection surfaces for bringing light fluxes from an object into focus on an image surface, wherein:

the reflection surfaces are arranged eccentrically; and

an F value in a plane containing vertices of the respective reflection surfaces is less than 1.9.

107 ~~108~~. (new) The multi-wavelength imaging device according to claim 39, wherein the reflective optical device comprising at least three reflection surfaces for bringing light fluxes from an object into focus on an image surface, wherein:

the reflection surfaces are arranged eccentrically;

among the reflection surfaces, the reflection surface placed second from the object side in a direction in which the light fluxes travel is given as a second reflection surface, and the second reflection surface is concave in a cross-sectional shape taken in the vicinity of its vertex along a plane containing vertices of the reflection surfaces, and is convex in a cross-sectional shape taken in a direction perpendicular to the plane.

REMARKS

The above preliminary amendment is made to remove multiple dependencies from claims 16-17, 32, 37, 40, 42, 83, 85-88, and 90. New claims 96-108 have also been added. In addition, typographical errors were removed from the specification. A marked-up copy of the specification and claims is attached.

A new abstract page is supplied to conform to that appearing on the publication page of the WIPO application, but the new Abstract is typed on a separate page as required by U.S. practice.

Applicants respectfully request that the preliminary amendment described herein be entered into the record prior to calculation of the filing fee and prior to examination and consideration of the above-identified application.

If a telephone conference would be helpful in resolving any issues concerning this communication, please contact Applicants' primary attorney-of record, Douglas P. Mueller (Reg. No. 30,300), at (612) 371.5237.

Respectfully submitted,

MERCHANT & GOULD P.C.
P.O. Box 2903
Minneapolis, Minnesota 55402-0903
(612) 332-5300

Dated: August 8, 2001

By______________________
Douglas P. Mueller
Reg. No. 30,300

DPM/jlc

MARKED-UP VERSION SHOWING CHANGES MADE

In the specification:

Paragraph beginning at page 42, line 21 has been amended as follows:

FIG. 18 is a view illustrating a configuration of a multi-wavelength imaging device according to a fourth embodiment of the present invention. Reference numerals 11 to 13 denote the same members as those in the third embodiment. In the fourth embodiment, the device further includes a wavelength selecting filter 15, an infrared imaging element 16, and a visible imaging element 17. The wavelength selecting filter 15 transmits only infrared rays (wavelength: 3μm to 5μm, or 8μm to 12μm) and reflects visible rays ~~(wavelength: 400μm to 750μm)~~ <u>(wavelength: 400nm to 750nm)</u>. The infrared imaging element 16 has sensitivity with respect to infrared rays, while the visible imaging element 17 has sensitivity with respect to visible rays.

Paragraph beginning at page 49, line 28 has been amended as follows:

FIG. 29 illustrates an example in which an imaging device 40 according to the present invention is mounted on a vehicle 41, so as to be used as a vehicle-mounted monitor including a vehicle-mounted visual supporting device. A situation ahead of a vehicle ~~92~~ <u>41</u> is imaged by an imaging device ~~70~~ <u>40</u>. By processing the image, it is possible to detect whether or not the vehicle is deviating from a traffic lane. Besides, by displaying the image on a display device (not shown) provided at a driving seat, it is possible to support human vision.

In the claims:

Claims 16-17, 32, 37, 40, 42, 83, 85-88, and 90 have been amended as follows:

16. (amended) The reflective optical device according to ~~any one of claims 11, 12, and 15,~~ claim 11, wherein the at least three reflection surfaces are non-axisymmetric surfaces.

17. (amended) The reflective optical device according to ~~any one of claims 11, 12, and 15,~~ claim 11, wherein the reflection surfaces are four surfaces that are a first surface, a second surface, a third surface, and a fourth surface in an order from the object side in a direction in which the light fluxes travel.

32. (amended) An imaging device, comprising:

the reflective optical device according to ~~any one of claims 1, 11, 12, and 15,~~ claim 1; and

a detecting means that converts a light intensity into an electric signal.

37. (amended) The multi-wavelength imaging device according to claim 35, wherein the reflective optical device is the reflective optical device ~~according to any one of claims 1, 11, 12, and 15.~~ comprising two non-axisymmetric reflection surfaces for bringing light fluxes from an object into focus on an image surface, the two non-axisymmetric reflection surfaces being a first reflection surface and a second reflection surface, wherein:

the first and second reflection surfaces are disposed in this order in a direction in which the light fluxes travel, and are arranged eccentrically; and

each of the first and second reflection surfaces is concave in a cross-sectional shape taken along a plane containing a center of the image surface and vertices of the reflection surfaces.

40. (amended) The multi-wavelength imaging device according to claim 39, wherein the reflective optical device is the reflective optical device ~~according to any one of claims 1, 11, 12, and 15.~~ comprising two non-axisymmetric reflection surfaces for bringing light fluxes from an object into focus on an image surface, the two non-axisymmetric reflection surfaces being a first reflection surface and a second reflection surface, wherein:

the first and second reflection surfaces are disposed in this order in a direction in which the light fluxes travel, and are arranged eccentrically; and

each of the first and second reflection surfaces is concave in a cross-sectional shape taken along a plane containing a center of the image surface and vertices of the reflection surfaces.

42. (amended) A vehicle-mounted monitor, comprising:

a multi-wavelength imaging device according to claim 35 ~~or 39~~; and

a display means that conveys an obtained image to a driver.

83. (amended) An imaging device, comprising the reflective optical device according to ~~any one of claims 43 to 76~~ claim 43, wherein an imaging element is provided at a portion of the reflective optical device where an image is formed.

85. (amended) An imaging device, comprising the reflective optical device according ~~to any one of claims 43 to 76~~ to claim 43, wherein an imaging element having sensitivity to a visible range is provided at a portion of the reflective optical device where an image is formed.

86. (amended) An imaging device, comprising the reflective optical device according ~~to any one of claims 43 to 59~~ to claim 43, wherein an imaging element having sensitivity to a visible range and an infrared range is provided at a portion of the reflective optical device where an image is formed.

87. (amended) An imaging device, comprising the reflective optical device according ~~to any one of claims 67, 68, 74, and 75~~ to claim 67, wherein an imaging element having sensitivity to a visible range and an infrared range is provided at a portion of the reflective optical device where an image is formed.

88. (amended) An imaging device, comprising the reflective solid-state optical device according to ~~any one of claims 77 to 82~~ to claim 77, wherein an imaging element is provided at a portion of the reflective solid-state optical device where an image is formed.

90. (amended) An imaging device, comprising the reflective solid-state optical device according to claim 81 ~~or 82~~, wherein an imaging element having sensitivity to a visible range and an infrared range is provided at a portion of the reflective solid-state optical device where an image is formed.

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DESCRIPTION

REFLECTIVE OPTICAL DEVICE, AND REFLECTIVE SOLID-STATE OPTICAL DEVICE, AND IMAGING DEVICE, MULTI-WAVELENGTH IMAGING ~~DEVICE, VIDEO CAMERA DEVICE, AND~~ VEHICLE-MOUNTED MONITOR UTILIZING THE SAME

TECHNICAL FIELD

The present invention relates to an optical system and an imaging device in each of which a reflection surface is used, and particularly relates to an imaging device making use of infrared rays.

BACKGROUND ART

Recently, research has been conducted on reflective optical devices mainly with a view to detection and imaging of infrared rays. In particular, for instance, JP-2763055B, JP-2598501B, and JP-2716933B propose various optical devices in each of which reflection surfaces are eccentrically disposed so that light fluxes are not blocked by the reflection surfaces on their ways but are effectively directed and imaged. Furthermore, a reflective optical device in which a reflection surface is formed to be a free-form surface, though not for use with infrared rays, is proposed by JP8(1996)-292371A, for instance.

As an imaging optical system for imaging image information in a visible range, a refractive optical system utilizing an optical glass as a lens has been used. An optical device having a plurality of reflection surfaces outside an optical medium that is a transparent body is proposed by JP11(1999)-14906.

On the other hand, in an optical device imaging a thermal image by utilizing infrared rays, since it deals with optical rays with wavelengths in the infrared range, a material used in a lens is selected from the group consisting of germanium, silicon, ZnSe, etc. An optical device having a lens formed with germanium and ZnSe is proposed by JP10(1998)-339842A. An optical device having a lens formed with germanium and silicon is proposed by JP1(1989)-88414A.

On the contrary, a reflective optical system is characterized in the

capability of image formation in a range from the visible range to the infrared range by appropriately selecting a material of a reflection surface. JP10(1998)-206986A proposes an optical device having a relay lens in addition to a coaxial reflective optical system with two reflection surfaces of a main mirror and a sub mirror.

A conventional optical system in which reflection surfaces are eccentrically arranged as described above, however, has a drawback in that optical specifications of brightness, resolution, distortion, an angle of view, etc. do not suffice for practical use.

Furthermore, in a conventional optical device for imaging image information in the visible range as described above, a refractive optical system requires a multiplicity of lenses for imaging image information in the visible range, thereby having a high cost. Furthermore, in an optical device in which reflection surfaces are provided outside a transparent optical medium, the number of component members required is decreased, but sufficient cost reduction cannot be achieved.

On the other hand, in the case where a refractive optical system is used in an optical device for forming a thermal image by utilizing infrared rays, the cost is high, and in some cases toxic materials such as germanium or ZnSe are used. In the case of a reflective optical system, the system can be made to have a relatively great numerical aperture without using specific materials, but reflection surfaces thereof per se tend to block light fluxes, thereby causing the optical system to have a small angle of view.

DISCLOSURE OF THE INVENTION

The present invention is to solve the above-described problems of the prior art, and an object of the present invention is to provide a reflective optical device and a reflective solid-state optical device, each of which achieves an increased angle of vision and improved optical performance, and is miniaturized and has reduced cost at the same time compatibly, as well as an imaging device, video camera device, and a vehicle-mounted monitor each of which utilizes the foregoing reflective optical device or reflective solid-state optical device.

To achieve the foregoing object, a first reflective optical device of the present invention is characterized by including two non-axisymmetric reflection surfaces for bringing light fluxes from an object into focus on an image surface. The two non-axisymmetric reflection surfaces are a first

reflection surface and a second reflection surface, and the first and second reflection surfaces are disposed in this order in a direction in which the light fluxes travel, and are arranged eccentrically. Each of the first and second reflection surfaces is concave in a cross-sectional shape taken along a plane containing a center of the image surface and vertices of the reflection surfaces. The foregoing reflective optical device includes two non-axisymmetric reflection surfaces that eccentrically are arranged, thereby allowing light fluxes to reach the image surface without being blocked, and hence allowing excellent image formation. Thus, a wide-angle and high-performance reflective optical device can be obtained.

The first reflective optical device preferably further includes a diaphragm for limiting light fluxes, the diaphragm being disposed between the first reflection surface and the object.

Furthermore, the first reflective optical device preferably satisfies the relationship expressed as below:

$$0.3 < d1/efy < 1.5$$

where d1 represents a distance between a center of the diaphragm and the vertex of the first reflection surface, and efy represents a focal length in a plane containing the center of the image surface and the vertices of the first and second reflection surfaces. When the foregoing formula is satisfied, it is possible to suppress occurrence of aberration, thereby preventing degradation of optical performance.

Furthermore, the first reflective optical device preferably satisfies the relationship expressed as below:

$$1.0 < d2/efy < 4.0$$

where d2 represents a distance between the vertex of the first reflection surface and the vertex of the second reflection surface, and efy represents a focal length in a plane containing the center of the image surface and the vertices of the first and second reflection surfaces. When the foregoing formula is satisfied, it is possible to suppress the occurrence of aberration, thereby preventing degradation of optical performance.

Furthermore, the first reflection surface preferably is concave in a cross-sectional shape taken in a direction perpendicular to a plane containing the center of the image surface and the vertices of the first and second reflection surfaces.

Furthermore, the second reflection surface preferably is concave in a cross-sectional shape taken in a direction perpendicular to a plane

containing the center of the image surface and the vertices of the first and second reflection surfaces.

Furthermore, each of the first and second reflection surfaces preferably is a free-form surface that does not have a rotational axis. The foregoing configuration of the reflective optical device allows freedom of design to be increased, while achieving an increased angle of vision and improved optical performance.

Furthermore, the free-form surface preferably is either a curved-axis Y toric surface or a curved-axis X toric surface, each of which is defined by a function f(X,Y) in a rectangular coordinate system (X, Y) in which the X direction is a direction perpendicular to a plane containing the center of the image surface and the vertices of the reflection surfaces and the Y direction is a direction of a tangent line at a vertex, the tangent line being contained in the foregoing plane. The curved-axis Y toric surface is such that a line obtained by connecting centers of radii of curvature of X-direction cross sections at respective Y coordinates is a curved line. The curved-axis X toric surface is such that a line obtained by connecting centers of radii of curvature of Y-direction cross sections at respective X coordinates is a curved line.

Furthermore, the first reflection surface preferably is a curved-axis Y toric surface or a curved-axis X toric surface, the curved-axis Y toric surface being such that a Y-direction cross section of the first reflection surface containing the vertex thereof is asymmetric with respect to a normal line at the vertex thereof, and a curved line connecting the centers of radii of curvature of the X-direction cross sections. With the foregoing configuration of the reflective optical device, the performance can be improved further.

Furthermore, the second reflection surface preferably is a curved-axis Y toric surface or a curved-axis X toric surface, the curved-axis Y toric surface being such that a Y-direction cross section of the first reflection surface containing the vertex thereof is asymmetric with respect to a normal line at the vertex thereof and a curved line connecting the centers of radii of curvature of the X-direction cross sections. According to the foregoing configuration of the reflective optical device, the performance can be improved further.

Next, a second reflective optical device of the present invention is characterized by including at least three reflection surfaces for bringing

light fluxes from an object into focus on an image surface. In the second reflective optical device, the reflection surfaces are arranged eccentrically, an F value in a plane containing vertices of the respective reflection surfaces is less than 3.5, and among the reflection surfaces, the two reflection surfaces on the object side are given as a first reflection surface and a second reflection surface, respectively, in an order from the object side in a direction in which the light fluxes travel, and each of the first and second reflection surfaces is concave in a cross-sectional shape taken along the plane. The reflective optical device configured as described above achieves improved optical performance compared with the two-mirror configuration, and hence, the device is applicable to a system with requirements of high resolution and high sensitivity.

Next, a third reflective optical device of the present invention is characterized by including at least three reflection surfaces for bringing light fluxes from an object into focus on an image surface. In the third reflective optical device, the reflection surfaces are arranged eccentrically, and an F value in a plane containing vertices of the respective reflection surfaces is less than 1.9. The reflective optical device configured as described above is applicable to a system with requirements of high resolution and high sensitivity.

In the third reflective optical device, the F value preferably is less than 1.6.

Furthermore, among the reflection surfaces, the two reflection surfaces on the object side are given as a first reflection surface and a second reflection surface, respectively, in an order from the object side in a direction in which the light fluxes travel, and each of the first and second reflection surfaces preferably is concave in a cross-sectional shape taken along the plane.

Next, a fourth reflective optical device comprises at least three reflection surfaces for bringing light fluxes from an object into focus on an image surface, and the reflection surfaces are arranged eccentrically. Among the reflection surfaces, the reflection surface placed second from the object side in a direction in which the light fluxes travel is given as a second reflection surface, and the second reflection surface is concave in a cross-sectional shape taken in the vicinity of its vertex along a plane containing vertices of the reflection surfaces, and is convex in a cross-sectional shape taken in a direction perpendicular to the plane. The

reflective optical device configured as described above is applicable to a system with requirements of higher resolution and higher sensitivity.

In the second, third, or fourth reflective optical device, the at least three reflection surfaces preferably are non-axisymmetric surfaces.

Furthermore, in the second, third, or fourth reflective optical device, the reflection surfaces preferably are four surfaces that are a first surface, a second surface, a third surface, and a fourth surface in an order from the object side in a direction in which the light fluxes travel.

The foregoing reflective optical device having four reflection surfaces preferably satisfies the relationship expressed as below:

$$26 < \alpha 3 < 56$$

where $\alpha 3$ represents an angle (deg) formed between a normal line of the third reflection surface at its vertex and an optical axis extended from the vertex of the third reflection surface to a vertex of the fourth reflection surface. In the case where $\alpha 3$ is lower than the lower limit of the range expressed by the above formula, a part of the light fluxes reflected by the fourth mirror returns to the reflection surface of the third mirror, which means the part is blocked and does not reach the image surface. In the case where $\alpha 3$ exceeds the upper limit of the foregoing range, a significant aberration occurs, thereby deteriorating the optical performance.

Furthermore, the foregoing reflective optical device preferably further includes a diaphragm for limiting the light fluxes, the diaphragm being disposed between the first reflection surface and the object.

Furthermore, the foregoing reflective optical device preferably satisfies the relationship expressed as below:

$$0.3 < d1/efy < 1.5$$

where d1 represents a distance between a center of the diaphragm and a vertex of the first reflection surface, and efy represents a focal length in the plane containing the vertices of the reflection surfaces.

Furthermore, the foregoing reflective optical device preferably satisfies the relationship expressed as below:

$$0.6 < d1/efy < 1.0$$

where d1 represents a distance between a center of the diaphragm and a vertex of the first reflection surface, and efy represents a focal length in the plane containing the vertices of the reflection surfaces.

Furthermore, the foregoing reflective optical device preferably satisfies the relationship expressed as below:

$$0.3 < d2/d4 < 1.0$$

where d2 represents a distance between a vertex of the first reflection surface and a vertex of the second reflection surface, and d4 represents a distance between a vertex of the third reflection surface and a vertex of the fourth reflection surface.

Furthermore, the foregoing reflective optical device preferably satisfies the relationship expressed as below:

$$2.6 < d4/efy < 7.5$$

where d4 represents a distance between a vertex of the third reflection surface and a vertex of the fourth reflection surface, and efy represents a focal length in the plane containing the vertices of the reflection surfaces.

Furthermore, the foregoing reflective optical device preferably satisfies the relationship expressed as below:

$$3.5 < d4/efy < 6.5$$

where d4 represents a distance between a vertex of the third reflection surface and a vertex of the fourth reflection surface, and efy represents a focal length in the plane containing the vertices of the reflection surfaces.

Furthermore, the foregoing reflective optical device preferably satisfies the relationship expressed as below:

$$0.5 < d5/efy < 2.0$$

where d5 represents a distance from a vertex of the fourth reflection surface to a center of an image surface, and efy represents a focal length in the plane containing the vertices of the reflection surfaces. When the foregoing relationships are satisfied, it is possible to avoid the blocking of a part of light fluxes by a reflection surface and the occurrence of aberration, thereby preventing optical performance from deteriorating.

Furthermore, each of the four reflection surfaces preferably is concave in a cross-sectional shape taken along the plane containing the vertices of the reflection surfaces.

Furthermore, among the reflection surfaces, the first reflection surface preferably is concave in a cross-sectional shape taken in a direction perpendicular to the plane containing the vertices of the reflection surfaces.

Furthermore, among the reflection surfaces, the third reflection surface preferably is concave in a cross sectional shape taken in a direction perpendicular to the plane containing the vertices of the reflection surfaces.

Furthermore, among the reflection surfaces, the fourth reflection surface preferably is concave in a cross-sectional shape taken in a direction

perpendicular to the plane containing the vertices of the reflection surfaces.

Furthermore, the fourth reflection surface preferably is a free-form surface that is in a non-axisymmetric form and that does not have a rotational axis.

Furthermore, the fourth reflection surface preferably is a free-form surface, and the free form surface preferably is either a curved-axis Y toric surface or a curved-axis X toric surface, each of which is defined by a function f(X,Y) in a rectangular coordinate system (X, Y) in which the X direction is a direction perpendicular to a plane containing the center of the image surface and the vertices of the reflection surfaces and the Y direction is a direction of a tangent line at a vertex, the tangent line being contained in the foregoing plane. The curved-axis Y toric surface is such that a line obtained by connecting centers of radii of curvature of the X-direction cross sections at respective Y coordinates is a curved line, and the curved-axis X toric surface is such that a line obtained by connecting centers of radii of curvature of the Y-direction cross sections at respective X coordinates is a curved line.

Next, a first imaging device of the present invention is characterized by including any one of the above-described reflective optical devices, and a detecting means that converts a light intensity into an electric signal. With the foregoing imaging device, it is possible to obtain wide-angle and high-resolution image signals.

In the first imaging device, the detecting means preferably is a two-dimensional imaging element.

Furthermore, the detecting means has sensitivity to light rays in an infrared range.

Next, a first multi-wavelength imaging device of the present invention is characterized by including a reflective optical device that converges light fluxes with only reflection surfaces, and a detecting means that has sensitivity to light rays in a plurality of different wavelength ranges. According to the foregoing configuration of the multi-wavelength imaging device, since light fluxes are converged by using only reflection surfaces, the device can be used with respect to light fluxes in any wavelength range, from the infrared range (wavelength: 3μm to 5μm, or 8μm to 12μm), the visible range (wavelength: 400nm to 750nm), to the ultraviolet range (wavelength: 200nm to 400nm). By combining the same with a detecting means with sensitivity to a plurality of wavelength ranges,

it is possible to form images in a plurality of wavelength ranges at the same time by use of one optical system. In the case where, for instance, the detecting means is sensitive to both the rays in the infrared range and in the visible range, it is possible to carry out image formation in the visible range that is suitable for image formation in the daytime and the image formation in the infrared range that is suitable for image formation at night.

In the first multi-wavelength imaging device, the plurality of different wavelength ranges preferably are not less than two wavelength ranges selected from an infrared range, a visible range, and an ultraviolet range.

Furthermore, the reflective optical device preferably is any one of the first, second, third, and fourth reflective optical devices.

Furthermore, the detecting means preferably includes a light flux separating means according to wavelengths, and a plurality of detecting surfaces that are responsive to the plurality of wavelength ranges, respectively.

Furthermore, the detecting means preferably includes, in the same detecting surface, a plurality of regions that have sensitivity to light rays in different wavelength ranges, respectively. With the multi-wavelength imaging device as described above, it is possible to form images in a plurality of wavelength ranges by using one optical system and one detecting element.

Furthermore, in a multi-wavelength imaging device that includes, in the same detecting surface, a plurality of regions that have sensitivity to light rays in different wavelength ranges, respectively, the reflective optical device preferably is any one of the first, second, third, and fourth reflective optical devices.

Next, a first vehicle-mounted monitor of the present invention is characterized by including the foregoing imaging device, and a display means that conveys an obtained image to a driver. With the vehicle-mounted monitor configured as described above, it is possible to obtain position information about a vehicle driving ahead, a pedestrian, etc. with high accuracy.

Next, a second vehicle-mounted monitor of the present invention is characterized by including the foregoing multi-wavelength imaging device, and a display means that conveys an obtained image to a driver.

Next, a fifth reflective optical device of the present invention is

characterized by including a plurality of optical members, each in a shell-like shape, that are opposed to each other and bonded integrally so that a hollow space is formed therein and that have at least one reflection surface on surfaces on hollow space sides. With the foregoing reflective optical device in which a plurality of shell-shaped optical members are opposed and bonded integrally, it is possible to achieve cost reduction and miniaturization both compatibly at the same time.

In the fifth reflective optical device, at least one of the reflection surface preferably is a free-form surface that does not have a rotational axis. Since the reflective optical device configured as described above includes a reflection surface that is a free-form surface, aberration-correcting capability of an eccentric optical system can be obtained, and hence, a configuration of an optical system with an optical path that conventionally has not been available is obtained. Furthermore, the blocking by the reflection surface itself is avoided, and an optical system with an increased angle of vision can be obtained.

Furthermore, the plurality of optical members preferably are two optical members that are a front optical member and a rear optical member, and the hollow space preferably is formed by providing the front optical member and the rear optical member integrally so that an opened side of the shell-like shape of the front optical member and an opened side of the shell-like shape of the rear optical member face and are bonded to each other.

Furthermore, the optical members preferably are resin moldings, and a metallic thin film preferably is formed on the reflection surface. This configuration allows the substantially whole structure to be formed with resin moldings, and metallic films to be formed only on the reflection surfaces. Therefore, it is possible to obtain a low-cost reflective optical device.

Furthermore, a material of the metallic thin film preferably is at least one selected from the group consisting of aluminum, gold, silver, copper and zinc.

Furthermore, a SiO_2 thin film preferably also is formed over the reflection surface. By thus configuring the reflective optical device, it is possible to prevent the reflectance from decreasing.

Furthermore, the optical members preferably are made of a metallic material.

Furthermore, the optical members preferably are made of at least one metallic material selected from the group consisting of aluminum, gold, silver, copper, and zinc.

Furthermore, a metallic thin film preferably is formed on the reflection surface of the optical members made of the metallic material. By thus configuring the reflective optical device, the device has an increased reflectance.

Furthermore, a material of the metallic thin film is at least one selected from the group consisting of aluminum, gold, silver, copper, and zinc.

Furthermore, in the reflective optical device in which a metallic thin film is formed on the reflection surface of the optical members made of the metallic material, a SiO_2 film preferably also is formed over the reflection surface. This configuration of the reflective optical device prevents the reflectance from decreasing.

Furthermore, in the fifth reflective optical device described above, at least one of the plurality of optical members preferably includes an aperture for image formation. In the reflective optical device configured as described above, it is possible to provide a window member at the aperture so that the window member transmits necessary light fluxes.

Furthermore, a window member that transmits light fluxes in a wavelength range necessary for image formation preferably is provided at the aperture for image formation. The reflective optical device allows necessary light fluxes to enter therein, and at the same time prevents dust and water droplets from entering from the external into the internal space of the hollow structure formed by integrally providing the plurality of optical members.

Furthermore, a window member that transmits light fluxes in a wavelength range necessary for image formation and that blocks light fluxes in the other wavelength ranges preferably is provided at the aperture for image formation. The reflective optical device configured as described above by no means allows light fluxes in an unnecessary wavelength range to enter the reflective optical device, thereby obtaining an image with an excellent contrast.

Furthermore, a window member made of a material selected from the group consisting of germanium, silicon, polyethylene, CaF_2, BaF_2, and ZnSe preferably is provided at the aperture for image formation. In the

case where germanium or silicon is used for forming the window member, it is possible to block light fluxes in the visible range while transmitting light fluxes in the infrared range. This enables the image formation by using light fluxes in the infrared range, which does not affect light fluxes in the visible range. In the case where polyethylene or ZnSe is used for forming the window member, it is possible to transmit light fluxes in the visible range and in the infrared range both, thereby making the image formation by using light fluxes in the visible range and in the infrared range both.

Furthermore, the window member preferably is in a flat plate form. This provides easy processing and cost reduction, and the adding of the same to the optical member is easy as well.

Furthermore, the window member preferably has a lens function. This makes it possible also to cause the window member to provide a part of the optical power contributing to the image formation, thereby enhancing the aberration correcting capability of the overall system, and further, improving the optical performance.

Furthermore, a window member that has an optical property of preventing at least infrared rays in a specific wavelength range among incident infrared rays from passing therethrough preferably is provided at the aperture for image formation. With the reflective optical device thus configured, it is possible to achieve cost reduction and miniaturization of the same at the same time compatibly, while it is possible to prevent light fluxes in unnecessary wavelength ranges from entering the reflective optical devices. Therefore, it is possible to obtain an image with an excellent contrast.

In the reflective optical device in which a window member that has an optical property of preventing at least infrared rays in a specific wavelength range among incident infrared rays from passing therethrough is provided at the aperture for image formation, the window member preferably has an optical property of reflecting infrared rays, and preferably is composed of a transparent base on which a dielectric multi-layer film is provided.

Furthermore, the transparent base preferably is made of a glass material.

Furthermore, the transparent base preferably is made of a resin material.

Furthermore, the transparent base preferably is made of at least one

selected from the group consisting of CaF_2, BaF_2, and ZnSe.

Furthermore, the window member preferably is made of a glass material having an optical property of absorbing infrared rays.

Furthermore, the window member preferably is made of a resin material having an optical property of absorbing infrared rays.

Furthermore, the window member preferably prevents infrared rays in a near infrared range from passing therethrough. With the reflective solid-state optical device thus configured, in the case where the member with photosensitivity has sensitivity to light fluxes in the visible and far infrared ranges both, it is possible to suppress the incidence of unnecessary components of light on the member having sensitivity to the respective wavelength ranges.

Furthermore, the near infrared range preferably is a range of 700nm to 1100nm.

Furthermore, the window member preferably is in a flat plate form. This provides easy processing and cost reduction, and the adding of the same to the optical member is easy as well.

Furthermore, the window member preferably has a lens function. This makes it possible to also cause the window member to provide a part of the optical power contributing to the image formation, thereby enhancing the aberration correcting capability of the overall system, and further, improving the optical performance.

Furthermore, a film having an optical property of not reflecting at least infrared rays in a specific wavelength range among incident infrared rays preferably is formed on each reflection surface. The reflective optical device thus configured allows only spectrum components necessary for image formation, among the light fluxes having entered through the aperture, to contribute to the image formation, thereby avoiding the light fluxes in an unnecessary wavelength range. As a result, an image with an excellent contrast can be obtained. Furthermore, it is possible to reduce the costs, since the device is composed of a decreased number of component parts.

In the reflective optical device in which a film having an optical property of not reflecting at least infrared rays in a specific wavelength range among incident infrared rays preferably is formed on each reflection surface, the film preferably has an optical property of not reflecting infrared rays in a range of wavelengths longer than those in a visible range. This

configuration of the reflective optical device allows the light fluxes used in image formation to be composed of only spectrum components in the visible range. Therefore, images with desirable color tones can be formed.

Furthermore, the range of wavelengths longer than those in the visible range preferably is a range of wavelengths longer than 700nm.

Furthermore, the film preferably has an optical property of not reflecting infrared rays in a near infrared range. According to the reflective optical device thus configured, in the case where the member with photosensitivity has sensitivity to light fluxes in the visible and far infrared ranges both, it is possible to suppress the incidence of unnecessary components of light to the member having sensitivity to the respective wavelength ranges.

Furthermore, the near infrared range preferably is a range of 700nm to 1100nm.

Furthermore, at least one of the plurality of optical members preferably includes an aperture for allowing an image to be formed on a member with photosensitivity.

Next, a first reflective solid-state optical device of the present invention is characterized by including a solid device body formed with an optical medium having an optical property of preventing at least infrared rays in a specific wavelength range among incident infrared rays from passing therethrough. On the device body, at least one reflection surface is formed, which is composed of a surface of the device body and a film formed on the surface of the device body. With the reflective optical device thus configured, it is possible to achieve cost reduction and miniaturization both at the same time compatibly.

In the first reflective solid-state optical device, the surface of the device body constituting the at least one reflection surface preferably is formed to be a free-form surface that does not have a rotational axis. Since the reflective optical device thus configured has a free-form surface as the reflection surface, aberration-correcting capability of an eccentric optical system can be obtained, and hence, a configuration of an optical system with an optical path that conventionally has not been available is obtained. Furthermore, the blocking by the reflection surface itself is avoided, and an optical system with an increased angle of vision can be obtained.

Furthermore, the optical medium preferably is made of a material having an optical property of preventing infrared rays in a range of

wavelengths longer than those in a visible range. This configuration of the reflective optical device allows the light fluxes used in image formation to be composed of only spectrum components in the visible range. Therefore, images with desirable color tones can be formed.

Furthermore, the range of wavelengths longer than those in the visible range preferably is a range of wavelengths longer than 700nm.

Furthermore, the optical medium preferably is made of a material having an optical property of preventing infrared rays in a near infrared range from passing therethrough. According to the configuration of the reflective solid-state optical device, it is possible to suppress the incidence of unnecessary components of light to members having sensitivity to the respective wavelength ranges.

Furthermore, the near infrared range preferably is a range of 700nm to 1100nm.

Next, a second imaging device of the present invention is characterized by including the fifth reflective optical device, wherein an imaging element is provided at a portion of the reflective optical device where an image is formed. In the case of the imaging device thus configured, it is possible to achieve miniaturization, cost reduction and improvement of contrast.

In the second imaging device, the imaging element preferably has sensitivity to a visible range.

Next, a third imaging device of the present invention is characterized by including the fifth reflective optical device, wherein an imaging element having sensitivity to a visible range is provided at a portion of the reflective optical device where an image is formed. In the case of the imaging device thus configured, it is possible to achieve miniaturization, cost reduction, and improvement of contrast.

Next, a fourth imaging device of the present invention is characterized by including the fifth reflective optical device, wherein an imaging element having sensitivity to a visible range and an infrared range is provided at a portion of the reflective optical device where an image is formed.

Next, a fifth imaging device of the present invention is characterized by including the aforementioned reflective optical device having the window member that prevents infrared rays in a near infrared range from passing therethrough, or including the aforementioned reflective optical device

having an optical property of not reflecting infrared rays in a near infrared range, wherein an imaging element having sensitivity to a visible range and an infrared range is provided at a portion of the reflective optical device where an image is formed.

Next, a sixth imaging device of the present invention is characterized by including the first reflective solid-state optical device, wherein an imaging element is provided at a portion of the reflective solid-state optical device where an image is formed. In the case of the imaging device thus configured, it is possible to achieve miniaturization, cost reduction, and improvement of contrast.

In the sixth imaging device, the imaging element preferably has sensitivity to a visible range.

Next, a seventh imaging device of the present invention is characterized by including a reflective solid-state optical device in which an optical medium is made of a material having an optical property of preventing infrared rays in a near infrared range from passing therethrough, wherein an imaging element having sensitivity to a visible range and an infrared range is provided at a portion of the reflective solid-state optical device where an image is formed.

Next, a first video camera device of the present invention is characterized by including the second imaging device.

Next, a second video camera device of the present invention is characterized by including the sixth imaging device. In the video camera thus configured, the imaging device is miniaturized and cost-reduced and is capable of achieving a high contrast. Therefore, the video camera device also can be miniaturized and cost-reduced, and exhibits high performance.

Next, a third vehicle-mounted monitor of the present invention is characterized by including the second imaging device.

Next, a fourth vehicle-mounted imaging device of the present invention is characterized by including the sixth imaging device. With the vehicle-mounted monitor thus configured, it is possible to detect the deviation of the vehicle from a traffic lane, a vehicle driving ahead, an obstacle ahead, etc. Besides, by displaying the image on a display device provided at a driving seat, it is possible to support human vision.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a view illustrating a configuration of a reflective optical

device according to a first embodiment of the present invention.

FIG. 2 is a perspective view for explaining a shape of a reflection surface.

FIG. 3 is an aberration diagram for illustrating the optical performance of the reflective optical device according to the first embodiment of the present invention.

FIG. 4 is an aberration diagram for illustrating the optical performance of the reflective optical device according to the first embodiment of the present invention.

FIG. 5 is a view illustrating a configuration of a reflective optical device according to a second embodiment of the present invention.

FIG. 6 is an aberration diagram for illustrating the optical performance of the reflective optical device according to the second embodiment of the present invention.

FIG. 7 is an aberration diagram for illustrating the optical performance of the reflective optical device according to the second embodiment of the present invention.

FIG. 8 is an aberration diagram for illustrating the optical performance of the reflective optical device according to the second embodiment of the present invention.

FIG. 9 is an aberration diagram for illustrating the optical performance of the reflective optical device according to the second embodiment of the present invention.

FIG. 10 is an aberration diagram for illustrating the optical performance of the reflective optical device according to the second embodiment of the present invention.

FIG. 11 is an aberration diagram for illustrating the optical performance of the reflective optical device according to the second embodiment of the present invention.

FIG. 12 is an aberration diagram for illustrating the optical performance of the reflective optical device according to the second embodiment of the present invention.

FIG. 13 is an aberration diagram for illustrating the optical performance of the reflective optical device according to the second embodiment of the present invention.

FIG. 14 is an aberration diagram for illustrating the optical performance of the reflective optical device according to the second

embodiment of the present invention.

FIG. 15 is an aberration diagram for illustrating the optical performance of the reflective optical device according to the second embodiment of the present invention.

FIG. 16 is an aberration diagram for illustrating the optical performance of the reflective optical device according to the second embodiment of the present invention.

FIG. 17 is a view illustrating a configuration of an imaging device according to a third embodiment of the present invention.

FIG. 18 is view illustrating a configuration of a multi-wavelength imaging device according to a fourth embodiment of the present invention.

FIG. 19 is a view illustrating a configuration of a multi-wavelength imaging device according to a fifth embodiment of the present invention.

FIG. 20 is a view illustrating a configuration of a vehicle-mounted monitor according to a sixth embodiment of the present invention.

FIG. 21 is a perspective view of a reflective optical device according to a seventh embodiment of the present invention.

FIG. 22 is a cross-sectional view of a reflective optical device according to the seventh embodiment of the present invention.

FIG. 23 is a cross-sectional view of another reflective optical device according to the seventh embodiment of the present invention.

FIG. 24 is a cross-sectional view of a reflective optical device according to an eighth embodiment of the present invention.

FIG. 25 is a cross-sectional view of a reflective optical device according to a ninth embodiment of the present invention.

FIG. 26 is a cross-sectional view of another reflective optical device according to the ninth embodiment of the present invention.

FIG. 27 is a cross-sectional view of a reflective optical device according to a tenth embodiment of the present invention.

FIG. 28 is a cross-sectional view of a reflective optical device according to an eleventh embodiment of the present invention.

FIG. 29 is a view illustrating an arrangement of a vehicle-mounted monitor utilizing an imaging device according to any one of the embodiments of the present invention.

FIG. 30 is a perspective view illustrating a configuration of a reflective optical device according to a twelfth embodiment of the present invention.

FIG. 31 is a cross-sectional view of a reflective optical device according to the twelfth embodiment of the present invention.

FIG. 32 is a cross-sectional view of a reflective optical device according to the twelfth embodiment of the present invention, which includes an aperture for image formation.

FIG. 33 is a cross-sectional view of another reflective optical device according to the twelfth embodiment of the present invention, which includes an aperture for image formation.

FIG. 34 is a cross-sectional view of a reflective optical device according to a thirteenth embodiment of the present invention.

FIG. 35 is a cross-sectional view of a reflective optical device according to the thirteenth embodiment of the present invention, which includes an aperture for image formation.

FIG. 36 is a cross-sectional view of another reflective optical device according to the thirteenth embodiment of the present invention, which includes an aperture for image formation.

FIG. 37 is a perspective view illustrating a configuration of a reflective optical device according to a fourteenth embodiment of the present invention.

FIG. 38 is a cross-sectional view of a reflective solid-state optical device according to a fourteenth embodiment of the present invention.

FIG. 39 is a cross-sectional view of another reflective solid-state optical device according to the fourteenth embodiment of the present invention.

FIG. 40 is a view schematically illustrating a configuration of a video camera device according to a fifteenth embodiment of the present invention.

BEST MODE FOR CARRYING OUT THE INVENTION

The following description will depict embodiments of the present invention, while referring to the drawings.

First Embodiment

FIG. 1 is a view illustrating a configuration of a reflective optical device according to a first embodiment of the present invention. The reflective optical device shown in the figure includes a diaphragm 1, a first mirror 2, a second mirror 3, and an image surface 4. The first mirror 2 and the second mirror 3 are arranged obliquely to the optical axes so that light

fluxes are reflected obliquely.

The foregoing figure illustrates a cross section of the reflective optical device taken along a plane containing the center of the image surface 4 and the vertices of the mirrors 2 and 3, which shows that the reflection surfaces of the mirrors 2 and 3 both are concave. Light fluxes from an object are limited by the diaphragm 1, reflected by the first and second mirrors 2 and 3, and then, projected to the image surface 4, where an image is formed.

Each of the respective surfaces of the first and second mirrors 2 and 3 is a non-axisymmetric surface: it is a surface whose normal line at a vertex is not an axis of rotational symmetry, unlike a normal spherical surface and an axisymmetric non-spherical surface. In the case where a reflection surface in the non-axisymmetric form is a free-form surface, the freedom of design is increased, the angle of view is widened, and the optical performance is enhanced. Here, the free-form surface means a surface that does not have a rotational axis like the rotational axis that a toric surface or the like possesses (this applies to the embodiments described below).

An example of the free-form surface is a curved-axis Y toric surface as shown in FIG. 2. The curved-axis Y toric surface is a surface as follows: in a rectangular coordinate system (X, Y) in which the X direction is a direction perpendicular to a plane containing a center of an image surface and each vertex and the Y direction is a direction of a tangent line at a vertex that is contained in the foregoing plane, a line obtained by connecting the centers of radii of curvature of the X-direction cross sections at respective Y coordinates is a curved line.

In FIG. 2, L1 denotes an X-direction cross section (arc), L2 denotes a line obtained by connecting X-direction curvatures (non-arc curved line), L3 denotes a Y-direction bus-bar shape (non-arc), and P denotes a vertex. Another example of a free-form surface is a curved-axis X toric surface in which X and Y are interchanged with each other.

With the premise that the vertex of the plane is the origin and the direction in which an incident light flux travels forward is positive, the curved-axis Y toric surface is expressed as a sag Z (mm) from the vertex at a point with the coordinates x(mm) and y (mm), which is expressed by the formulae (1) through (5) shown below:

Formula (1)

$$Z = M(y) + S(x, y)$$

Formula (2)

$$M(y) = \frac{\left(\dfrac{y^2}{Rdy}\right)}{1+\sqrt{1-\left(\dfrac{y}{Rdy}\right)^2}}$$

$$+ YAD\ y^4 + YAE\ y^6 + YAF\ y^8 + YAG\ y^{10}$$

$$+ YAOD\ y^3 + YAOE\ y^5 + YAOF\ y^7 + YAOG\ y^9$$

Formula (3)

$$S(x,y) = \frac{\dfrac{x^2}{Rds} - 2x \cdot \sin\theta}{\cos\theta + \sqrt{\cos^2\theta - \left(\dfrac{x}{Rds}\right)^2 + \dfrac{2x \cdot \sin\theta}{Rds}}}$$

$$+ XAD\ x^4 + XAE\ x^6 + XAF\ x^8 + XAG\ x^{10}$$

Formula (4)

$$Rds = Rdx(1+BCy^2+BDy^4+BEy^6+BFy^8+BGy^{10}+BOCy+$$
$$+BODy^3+BOEy^5+BOFy^7+BOGy^9)$$

Formula (5)

$$\theta = QCy^2+QDy^4+QEy^6$$

where:

M(y) represents an expression that expresses a non-arc as a Y-direction cross section containing the vertex, Rdy(mm) represents a radius

of curvature in theY direction, YAD, YAE, YAF, and YAG represent even-order constants contributing in the Y direction, respectively, and YAOD, YAOE, YAOF, and YAOG represent odd-order constants, respectively; and

S(x, y) represents an expression that expresses an X-direction cross section, Rds represents a function that expresses a radius of curvature in the X direction at each y coordinate, Rdx(mm) represents a radius of curvature in the X direction at the center, BC, BD, BE, BF, and BG represent even-order constants, respectively, BOC, BOD, BOE, BOF, and BOG represent odd-order constants, respectively, XAD, XAE, XAF, and XAG represent even-order constants contributing in the X direction, respectively, θ(rad) represents a function that determines a twist angle of the surface, and QC, QD, and QE represent twist coefficients, respectively.

Likewise, with the premise that the vertex of the plane is the origin and the direction in which an incident light flux travels forward is positive, the curved-axis X toric surface is expressed as a sag Z (mm) from the vertex at a point with the coordinates x(mm) and y (mm), which is expressed by the formulae (6) through (10) shown below:

Formula (6)

$$Z = M(x) + S(x, y)$$

Formula (7)

$$M(x) = \frac{\left(\frac{x^2}{Rdx}\right)}{1+\sqrt{1-\left(\frac{x}{Rdx}\right)^2}} + XAD\,x^4 + XAE\,x^6 + XAF\,x^8 + XAG\,x^{10}$$

Formula (8)

$$S(x,y) = \frac{\dfrac{y^2}{Rds} - 2y \cdot \sin\theta}{\cos\theta + \sqrt{\cos^2\theta - \left(\dfrac{y}{Rds}\right)^2 + \dfrac{2y \cdot \sin\theta}{Rds}}}$$

$$+ YAD\,y^4 + YAE\,y^6 + YAF\,y^8 + YAG\,y^{10}$$

$$+ YAOD\,y^3 + YAOE\,y^5 + YAOF\,y^7 + YAOG\,y^9$$

Formula (9)

$$Rds = Rdy(1 + BCx^2 + BDx^4 + BEx^6 + BFx^8 + BGx^{10} + BOCx + {} + BODx^3 + BOEx^5 + BOFx^7 + BOGx^9)$$

Formula (10)

$$\theta = QCx^2 + QDx^4 + QEx^6$$

where:

M(x) represents an expression that expresses a non-arc as a X-direction cross section containing the vertex, S(x, y) represents an expression that expresses a Y-direction cross section;

Rdx(mm) represents a radius of curvature in the X direction, XAD, XAE, XAF, and XAG represent even-order constants contributing in the X direction, respectively; and

Rds represents a function that expresses a radius of curvature in the Y direction at each x coordinate, Rdy(mm) represents a radius of curvature in the Y direction at the center, BC, BD, BE, BF, and BG represent even-order constants, respectively, BOC, BOD, BOE, BOF, and BOG represent odd-order constants, respectively, YAD, YAE, YAF, and YAG represent even-order constants contributing in the Y direction, respectively, YAOD, YAOE, YAOF, and YAOG represent odd-order constants, respectively, BOC, BOD, BOE, BOF, and BOG represent odd-order constants, respectively, θ(rad) represents a function that determines a twist angle of the surface, and QC, QD, and QE represent twist coefficients, respectively.

Furthermore, the relationship expressed by the formula (11) below preferably is satisfied:

Formula (11) $0.3 < d1/efy < 1.5$

where d1 represents a distance between a center of the diaphragm and the vertex of the first mirror 2, and efy represents a focal length in a plane containing the center of the image surface 4 and the vertices of the first and second mirrors 2 and 3.

Furthermore, the relationship expressed by the formula (12) below preferably is satisfied:

Formula (12) $1.0 < d2/efy < 4.0$

where d2 represents a distance between the vertex of the first mirror 2 and the vertex of the second mirror 3.

When the formulae (11) and (12) are satisfied, it is possible to suppress aberration, thereby preventing deterioration of the optical performance.

Tables 1 and 2 show examples of concrete numerical values in the present embodiment. In the tables, M1 and M2 indicate the first mirror 2 and the second mirror 3, respectively. In Table 1, M1 and M2 both have curved-axis Y toric surfaces, respectively, while in Table 2, M1 and M2 both have curved-axis X toric surfaces, respectively.

Further, efy represents a focal length of the entire system in the y direction, efx represents a focal length of the entire system in the x direction, d1 represents a distance (mm) from the center of the diaphragm 1 to the vertex of the first mirror 2, d2 represents a distance (mm) from the vertex of the first mirror 2 to the vertex of the second mirror 3, d3 represents a distance (mm) from the vertex of the second mirror 3 to the image surface 4, $\alpha 1$ represents an angle (deg) formed by a normal line of the first mirror 2 and the optical axis, and $\alpha 2$ represents an angle (deg) formed by a normal line of the second mirror 3 and the optical axis. In the examples shown in Table 2, the image surface is arranged with a tilt with respect to the optical axis, and the angle is set to $\alpha 3$.

In the examples shown in Tables 1 and 2, Rdy of M1 and that of M2 are both negative. This means that the surfaces of M1 and M2 both are concave in the Y direction (this applies to the examples shown in Tables 3 through 13). Besides, Rdx of M1 and that of M2 are both negative. This means that the surfaces of M1 and M2 both are concave in the X direction.

TABLE 1

efy=8.59 efx=29.58

Diaphragm	ϕ 2.0
	d1 : 6.61
M1	α1 : 30 rdy:−15.07698 rdx:−161.387 YAD:1.4254×10^{-5} YAOD:-7.5192×10^{-4} YAOE:1.6213×10^{-5} BC:9.2330×10^{-3} BOD:3.4719×10^{-3}
	d2 : 23.41
M2	α2 : 30 rdy:−22.108 rdx:−56.202 YAD:-2.2097×10^{-5} YAOD:3.3323×10^{-4} YAOE:2.7018×10^{-7} BC:-1.7039×10^{-3} BOD:7.7878×10^{-5}
	d3 : 22.16
Image Surface	α3 : 0

TABLE 2

efy=9.75 efx=24.94

Diaphragm	ϕ 3.0
	d1 : 8.15
M1	α 1 : 30 rdy:−15.40531 rdx:−78.23718 YAD:-1.11104×10^{-6} YAE:-7.94940×10^{-6} YAF:3.20283×10^{-7} YAG:5.58089×10^{-10} YAOD:1.28434×10^{-3} YAOE:1.02160×10^{-5} YAOF:-3.52620×10^{-7} YAOG:1.28002×10^{-8} XAD:2.97163×10^{-5} XAE:2.42403×10^{-6} BC:-4.08445×10^{-4} BD:-1.37960×10^{-4} QC:1.45193×10^{-4} QD:-2.89601×10^{-6}
	d2 : 17.89
M2	α 2 : 30 rdy:−14.82636 rdx:−58.27511 YAD:-1.41004×10^{-5} YAE:8.10057×10^{-7} YAF:1.08431×10^{-8} YAG:-3.22948×10^{-9} YAOD:-2.08556×10^{-4} YAOE:3.49859×10^{-6} YAOF:-9.93788×10^{-8} YAOG:-3.43238×10^{-9} XAD:9.91702×10^{-7} XAE:-1.65342×10^{-6} BC:-8.01946×10^{-4} BD:3.67792×10^{-5} QC:-3.07422×10^{-4} QD:-1.64131×10^{-6}
	d3 : 15.02
Image Surface	α 3 : 23.74

According to the present embodiment, two mirrors with curved-axis toric surfaces, each of which has a high-level capability of aberration correction, are eccentrically arranged. Therefore, it is possible to guide light fluxes to an image surface without blocking the same, thereby allowing excellent image formation. Thus, it is possible to provide a high-performance reflective optical device with a wider angle of view. FIGS. 3 and 4 illustrate the examples shown in Tables 1 and 2.

Incidentally, in the present embodiment, the shape of the mirror surface is that defined by the formulae (1) through (5), or that defined by the formulae (6) through (10), but it may be a surface in a form defined by different formulae as long as it is a similar surface.

Second Embodiment

FIG. 5 is a view illustrating a configuration of a reflective optical device according to a second embodiment of the present invention. The reflective optical device shown in the figure includes a diaphragm 5, a first mirror 6, a second mirror 7, a third mirror 8, a fourth mirror 9, and an image surface 10. The mirrors 6 to 9 are arranged obliquely to the optical axes so that light fluxes are reflected obliquely. Light fluxes from an object are limited by the diaphragm 5, reflected by the mirrors 6 to 9, and then projected to the image surface 10, where an image is formed.

The foregoing figure illustrates a cross section of the reflective optical device taken along a plane containing the vertices of the mirrors6 to 9, and the reflection surfaces of the mirrors 6 to 9 all are concave.

Each of the respective surfaces of the mirrors 6 to 9 is either the curved-axis Y toric surface (the formulae (1) to (5)), or the curved-axis X toric surface (the formulae (6) to (10)).

In the present embodiment, the relationship expressed by the formula (13) below preferably is satisfied:

Formula (13) $26 < \alpha 3 < 56$

where $\alpha 3$ represents an angle (deg) formed by a normal line of the third mirror 8 at the vertex and an optical axis directed from the vertex of the third mirror 8 to the vertex of the fourth mirror 9.

In the case where $\alpha 3$ is lower than the lower limit of the range expressed by the formula (13), a part of the light fluxes reflected by the fourth mirror 9 returns to the reflection surface of the third mirror 8, which

means the part is blocked and does not reach the image surface. In the case where $\alpha 3$ exceeds the upper limit of the foregoing range, a significant aberration occurs, thereby deteriorating the optical performance.

Further, the relationship expressed by the formula (14) below preferably is satisfied:

Formula (14) $0.3 < d1/efy < 1.5$

where d1 represents a distance between the center of the diaphragm and the vertex of the first mirror 6, and efy represents a focal length in a plane containing the vertices of the reflection surfaces.

The range defined by the formula (14) preferably is further limited as expressed by the formula (15) below:

Formula (15) $0.6 < d1/efy < 1.0$

Furthermore, the relationship expressed by the formula (16) below preferably is satisfied:

Formula (16) $0.3 < d2/d4 < 1.0$

where d2 represents a distance between the vertex of the first mirror 6 and the vertex of the reflection surface of the second mirror 7, and d4 represents a distance between the vertex of the reflection surface of the third mirror 8 and the vertex of the reflection surface of the fourth mirror 9.

Furthermore, the relationship expressed by the formula (17) below preferably is satisfied:

Formula (17) $2.6 < d4/efy < 7.5$

where d4 represents a distance between the vertex of the reflection surface of the third mirror 8 and the vertex of the reflection surface of the fourth mirror 9.

Furthermore, the range defined by the formula (17) preferably is further limited as expressed by the formula (18) below:

Formula (18) $3.5 < d4/efy < 6.5$

The relationship expressed by the formula (19) below preferably is satisfied:

Formula (19) $0.5 < d5/efy < 2.0$

When the formulae (13) through (19) are satisfied, it is possible to suppress the blocking of a part of light fluxes at the reflection surfaces, and aberration. Therefore, deterioration of the optical performance can be prevented.

Tables 3 through 13 show examples of concrete numerical values in the present embodiment. In the tables, M1, M2, M3, and M4 indicate the first mirror 6, the second mirror 7, the third mirror 8, and the fourth mirror 9, respectively. In the examples shown in Tables 4 through 9, each of M1 through M4 has a curved-axis X toric surface. In the examples shown in Tables 10 through 12, M1 and M4 have curved-axis X toric surfaces, respectively, while in the example shown in Table 13, M1 has a curved-axis X toric surface, while M2 through M4 have curved-axis Y toric surfaces, respectively.

Further, efy represents a focal length of the entire system in the y direction, efx represents a focal length of the entire system in the x direction, d1 represents a distance (mm) from the center of the diaphragm 5 to the vertex of the first mirror 6, d2 represents a distance (mm) from the vertex of the first mirror 6 to the vertex of the second mirror 7, d3 represents a distance (mm) from the vertex of the second mirror 7 to the vertex of the third mirror 8, d4 represents a distance (mm) from the vertex of the third mirror 8 to the vertex of the fourth mirror 9, and d5 represents a distance (mm) from the vertex of the fourth mirror 9 to the center of the image surface 10.

$\alpha 1$ through $\alpha 4$ represent angles (deg) formed by normal lines of the first through fourth mirrors 6 through 9 and the optical axis, respectively. In each of the examples shown in Tables 10 to 13, the image surface is arranged with a tilt with respect to the optical axis, and the angle is set to $\alpha 5$.

TABLE 3

efy=6.0 efx=6.0

Diaphragm	ϕ 2.0
	d1 : 7.50
M1	α1 : 28 rdy:−20.77944 rdx:−15.70431 YAD:2.85520×10^{-5} YAE:-8.45180×10^{-7} YAOD:2.43998×10^{-4} YAOE:4.71315×10^{-6} BC:-1.65813×10^{-2} BD:5.07453×10^{-4} QC:-1.25276×10^{-3} QD:1.17284×10^{-8}
	d2 : 9.85
M2	α2 : 35 rdy:−18.03572 rdx:−10.59307 YAD:3.91994×10^{-4} YAE:8.72308×10^{-6} YAOD:-1.75571×10^{-3} YAOE:2.81540×10^{-5} BC:-6.55252×10^{-2} BD:2.20923×10^{-2} QC:3.29483×10^{-3} QD:-3.09511×10^{-8}
	d3 : 23.74
M3	α3 : 26 rdy:−40.34396 rdx:−34.87208 YAD:-1.68810×10^{-6} YAE:4.38391×10^{-7} YAOD:-2.29194×10^{-4} YAOE:8.63287×10^{-7} BC:-1.84078×10^{-3} BD:7.01830×10^{-5} QC:-9.50937×10^{-6} QD:-3.93368×10^{-6}
	d4 : 12.81
M4	α4 : 21.35 rdy:−31.02412 rdx:−25.47785 YAD:1.02141×10^{-5} YAE:-1.12296×10^{-7} YAOD:3.51527×10^{-4} YAOE:-8.51782×10^{-7} BC:1.53260×10^{-3} BD:7.67259×10^{-6}
	d5 : 11.37
Image Surface	α5 : 0.0

TABLE 4

efy=6.0 efx=6.0

Diaphragm	ϕ 3.0
	d1 : 7.50
M1	α1 : 28 rdy:−21.82217 rdx:−14.82874 YAD:-1.19714×10^{-5} YAE:5.60805×10^{-7} YAOD:4.98348×10^{-4} YAOE:-5.31684×10^{-6} BC:-1.33865×10^{-2} BD:2.52256×10^{-4} QC:-3.39625×10^{-3} QD:1.17285×10^{-8}
	d2 : 9.85
M2	α2 : 35 rdy:−17.91289 rdx:−11.48710 YAD:4.22895×10^{-4} YAE:9.22965×10^{-6} YAOD:-2.44954×10^{-3} YAOE:4.42684×10^{-5} BC:-5.93678×10^{-2} BD:1.23542×10^{-2} QC:3.79637×10^{-3} QD:-3.09512×10^{-8}
	d3 : 23.74
M3	α3 : 40 rdy:−44.95284 rdx:−31.58477 YAD:-2.83072×10^{-6} YAE:4.09973×10^{-7} YAOD:-2.19463×10^{-4} YAOE:2.58538×10^{-6} BC:4.25959×10^{-4} BD:4.46018×10^{-5} QC:-2.88240×10^{-4} QD:-3.63034×10^{-6}
	d4 : 12.91
M4	α4 : 24.31 rdy:−33.08792 rdx:−24.70912 YAD:3.40138×10^{-6} YAE:-1.29774×10^{-7} YAOD:3.86085×10^{-4} YAOE:-2.03534×10^{-6} BC:2.27858×10^{-3} BD:-7.72750×10^{-5}
	d5 : 11.52
Image Surface	α5 : 0.0

TABLE 5

efy=6.0 efx=6.0

Diaphragm	ϕ 2.0
	d1 : 7.50
M1	α 1 : 28 rdy:−22.39173 rdx:−13.80661 YAD:-3.09321×10^{-5} YAE:8.16600×10^{-7} YAOD:3.33310×10^{-4} YAOE:-7.15611×10^{-7} BC:-2.03056×10^{-2} BD:2.27089×10^{-4} QC:-5.43622×10^{-3} QD:1.17284×10^{-8}
	d2 : 9.85
M2	α 2 : 35 rdy:−18.11807 rdx:−10.42351 YAD:3.92243×10^{-4} YAE:5.97963×10^{-6} YAOD:-2.13483×10^{-3} YAOE:5.53745×10^{-5} BC:-5.41481×10^{-2} BD:9.17823×10^{-3} QC:2.94190×10^{-3} QD:-3.09513×10^{-8}
	d3 : 23.74
M3	α 3 : 56 rdy:−61.81877 rdx:−27.32216 YAD:-5.16440×10^{-6} YAE:3.06650×10^{-7} YAOD:-1.98648×10^{-4} YAOE:3.07233×10^{-6} BC:-1.76257×10^{-3} BD:5.10835×10^{-5} QC:-5.39013×10^{-4} QD:-8.07966×10^{-6}
	d4 : 11.95
M4	α 4 : 24.72 rdy:−33.34237 rdx:−22.94313 YAD:2.12146×10^{-6} YAE:-1.87215×10^{-8} YAOD:6.17948×10^{-4} YAOE:-2.40465×10^{-6} BC:2.25609×10^{-3} BD:-6.38015×10^{-5}
	d5 : 11.71
Image Surface	α 5 : 0.0

TABLE 6

efy=6.0 efx=6.0

Diaphragm	ϕ1.75
	d1 : 2.0
M1	α1 : 39 rdy:−28.99836 rdx:−12.39711 YAD:-3.01369×10^{-4} YAE:2.77086×10^{-5} YAOD:1.66612×10^{-3} YAOE:-8.14946×10^{-5} BC:-1.61540×10^{-1} BD:4.96420×10^{-2} QC:-3.95368×10^{-3} QD:1.17285×10^{-8}
	d2 : 9.85
M2	α2 : 35 rdy:−15.77873 rdx:−8.89741 YAD:5.86027×10^{-4} YAE:-3.01663×10^{-6} YAOD:-8.20487×10^{-4} YAOE:-1.48207×10^{-5} BC:-3.01679×10^{-2} BD:2.32177×10^{-3} QC:1.76844×10^{-3} QD:-3.09511×10^{-8}
	d3 : 23.74
M3	α3 : 40 rdy:−42.80333 rdx:−34.42642 YAD:-1.30380×10^{-5} YAE:3.96163×10^{-7} YAOD:-1.02025×10^{-5} YAOE:1.67535×10^{-6} BC:4.16640×10^{-4} BD:-5.77840×10^{-5} QC:-3.33973×10^{-4} QD:7.95418×10^{-7}
	d4 : 12.60
M4	α4 : 23.08 rdy:−32.65172 rdx:−23.03887 YAD:6.74044×10^{-6} YAE:-2.36405×10^{-7} YAOD:3.81289×10^{-4} YAOE:-1.93378×10^{-6} BC:-3.78634×10^{-4} BD:1.58382×10^{-4}
	d5 : 11.20
Image Surface	α5 : 0.0

TABLE 7

efy=6.0 efx=6.0

Diaphragm	ϕ 3.0
	d1 : 5.50
M1	α1 : 28 rdy:−24.17387 rdx:−14.31709 YAD:-1.02173×10^{-4} YAE:4.26096×10^{-6} YAOD:1.07186×10^{-3} YAOE:-2.49497×10^{-5} BC:-2.50958×10^{-2} BD:5.28022×10^{-4} QC:-4.20192×10^{-3} QD:1.17285×10^{-8}
	d2 : 9.85
M2	α2 : 35 rdy:−15.94181 rdx:−9.66194 YAD:3.92719×10^{-4} YAE:5.56002×10^{-6} YAOD:-1.63499×10^{-3} YAOE:2.45322×10^{-6} BC:-5.96184×10^{-2} BD:1.30828×10^{-2} QC:5.41429×10^{-3} QD:-3.09512×10^{-8}
	d3 : 23.74
M3	α3 : 40 rdy:−44.89417 rdx:−34.86430 YAD:-2.12356×10^{-6} YAE:3.94434×10^{-7} YAOD:-1.95436×10^{-4} YAOE:2.26073×10^{-6} BC:7.21681×10^{-5} BD:5.60464×10^{-5} QC:-3.21340×10^{-4} QD:-4.50268×10^{-6}
	d4 : 12.41
M4	α4 : 23.36 rdy:−31.80780 rdx:−23.20315 YAD:7.07410×10^{-6} YAE:-1.51771×10^{-7} YAOD:4.05762×10^{-4} YAOE:-2.04428×10^{-6} BC:5.22411×10^{-4} BD:1.05700×10^{-5}
	d5 : 11.40
Image Surface	α5 : 0.0

TABLE 8

efy=6.0 efx=6.0

Diaphragm	ϕ 2.0
	d1 : 9.0
M1	α1 : 32 rdy:−23.40328 rdx:−14.37048 YAD:-4.53336×10^{-5} YAE:9.51679×10^{-7} YAOD:4.17810×10^{-4} YAOE:-5.34064×10^{-6} BC:-1.33642×10^{-2} BD:4.16406×10^{-4} QC:-1.82225×10^{-3} QD:1.17286×10^{-8}
	d2 : 9.85
M2	α2 : 37 rdy:−17.87708 rdx:−10.95019 YAD:4.25988×10^{-4} YAE:1.03962×10^{-5} YAOD:-2.02336×10^{-3} YAOE:4.20681×10^{-5} BC:-4.47247×10^{-2} BD:1.66161×10^{-2} QC:3.78534×10^{-3} QD:-3.09512×10^{-8}
	d3 : 23.74
M3	α3 : 40 rdy:−45.06124 rdx:−31.98407 YAD:-2.50736×10^{-6} YAE:3.94618×10^{-7} YAOD:-1.93104×10^{-4} YAOE:2.45156×10^{-6} BC:2.04538×10^{-6} BD:4.21346×10^{-5} QC:-2.06813×10^{-4} QD:-3.07224×10^{-6}
	d4 : 12.83
M4	α4 : 22.89 rdy:−32.45308 rdx:−24.64244 YAD:3.70972×10^{-6} YAE:-1.48635×10^{-7} YAOD:4.09804×10^{-4} YAOE:-2.28830×10^{-6} BC:1.65169×10^{-3} BD:-2.43063×10^{-5}
	d5 : 11.56
Image Surface	α5 : 0.0

TABLE 9

efy=6.0 efx=6.0

Diaphragm	ϕ 4.0
	d1 : 5.50
M1	α1 : 40 rdy:−66.14546 rdx:−12.38682 YAD:-1.10756×10^{-4} YAE:3.65584×10^{-7} YAOD:5.82227×10^{-4} YAOE:2.42221×10^{-6} BC:-1.74578×10^{-2} BD:1.64602×10^{-3} QC:-1.50452×10^{-3} QD:4.79608×10^{-5}
	d2 : 14.2
M2	α2 : 40 rdy:−13.89106 rdx:−14.47631 YAD:5.92504×10^{-4} YAE:-3.84669×10^{-6} YAOD:-8.85563×10^{-4} YAOE:9.39882×10^{-6} BC:-3.18752×10^{-3} BD:-1.00143×10^{-5} QC:-1.47114×10^{-3} QD:-1.23368×10^{-5}
	d3 : 29.61
M3	α3 : 40 rdy:−53.05799 rdx:−72.28070 YAD:3.52465×10^{-6} YAE:5.03647×10^{-8} YAOD:-1.69773×10^{-4} YAOE:-5.00443×10^{-7} BC:3.64224×10^{-3} BD:1.24747×10^{-5} QC:-1.13319×10^{-4} QD:-1.94595×10^{-7}
	d4 : 16.0
M4	α4 : 24 rdy:−29.68662 rdx:−20.89002 YAD:1.94548×10^{-5} YAE:-2.69948×10^{-7} YAOD:5.36908×10^{-4} YAOE:-4.24714×10^{-6} BC:-1.04264×10^{-3} BD:2.25904×10^{-5}
	d5 : 11.107
Image Surface	α5 : 0.0

TABLE 10

efy=4.95 efx=8.2

Diaphragm	ϕ 3.0
	d1 : 3.70
M1	α1 : 45 rdy:−28.99984 rdx:−152.90201 YAD:1.02760×10^{-4} YAE:2.99852×10^{-6} YAOD:4.79855×10^{-4} YAOE:-4.17507×10^{-5} XAD:-1.36455×10^{-4} XAE:-5.95804×10^{-6} BC:8.13423×10^{-3} BD:-9.77759×10^{-4} BE:-1.00790×10^{-4} QC:1.80359×10^{-4} QD:-3.29024×10^{-6} QE:-1.77485×10^{-5}
	d2 : 9.6
M2	α2 : 45 rdy:−37.56346 rdx:37.86628 YAD:1.53014×10^{-6} YAE:5.28690×10^{-8} YAOD:5.67901×10^{-5} YAOE:7.36468×10^{-7} BC:6.07494×10^{-3} BD:2.66522×10^{-4} BE:5.04359×10^{-7} BOC:-9.43947×10^{-2} BOD:-1.73317×10^{-3} BOE:-1.64912×10^{-5}
	d3 : 21.93
M3	α3 : 37.5 rdy:−42.02344 rdx:−15.28639 YAD:5.61442×10^{-7} YAE:7.00253×10^{-8} YAOD:3.89467×10^{-5} YAOE:6.00934×10^{-7} BC:-1.21973×10^{-3} BD:-1.09018×10^{-6} BE:-6.01116×10^{-9} BOC:-9.84872×10^{-3} BOD:3.85896×10^{-5} BOE:1.54447×10^{-7}
	d4 : 19.0
M4	α4 : 30 rdy:−21.02911 rdx:−6.57700 YAD:-1.34023×10^{-4} YAE:3.82257×10^{-6} YAF:-1.65579×10^{-7} YAG:6.41753×10^{-10} YAOD:-2.59123×10^{-4} YAOE:-2.53186×10^{-5} YAOF:2.98831×10^{-7} YAOG:-1.17970×10^{-8} XAD:7.69818×10^{-5} XAE:5.27296×10^{-6} BC:-1.82143×10^{-2} BD:-1.26425×10^{-4} BE:6.71129×10^{-6} QC:4.75773×10^{-4} QD:2.40033×10^{-5} QE:-3.64543×10^{-7}
	d5 : 7.7
Image Surface	α5 : 16

TABLE 11

efy=4.95 efx=8.2

Diaphragm	ϕ 3.5
	d1 : 3.70
M1	α1 : 45 rdy:−28.36101 rdx:−106.68403 YAD:1.10697×10^{-4} YAE:2.99391×10^{-6} YAOD:5.79682×10^{-4} YAOE:-4.14654×10^{-5} XAD:-1.29369×10^{-4} XAE:3.35450×10^{-7} BC:1.11679×10^{-2} BD:6.83405×10^{-4} BE:-7.47472×10^{-5} QC:-3.87840×10^{-4} QD:3.81498×10^{-5} QE:-2.08261×10^{-6}
	d2 : 9.6
M2	α2 : 45 rdy:−39.31311 rdx:27.92454 YAD:2.16018×10^{-7} YAE:2.99374×10^{-8} YAOD:5.60292×10^{-5} YAOE:7.09183×10^{-7} BC:7.55866×10^{-3} BD:2.71136×10^{-4} BE:2.69578×10^{-7} BOC:-7.07328×10^{-2} BOD:-1.68621×10^{-3} BOE:-1.72513×10^{-5}
	d3 : 22.15
M3	α3 : 37.5 rdy:−43.63003 rdx:−17.35842 YAD:7.18754×10^{-7} YAE:5.41462×10^{-8} YAOD:4.82396×10^{-5} YAOE:6.70946×10^{-7} BC:-9.91360×10^{-4} BD:-7.75342×10^{-7} BE:-7.57007×10^{-9} BOC:-5.65695×10^{-3} BOD:4.13483×10^{-5} BOE:1.39542×10^{-8}
	d4 : 22.5
M4	α4 : 30 rdy:−20.71904 rdx:−7.03109 YAD:-1.30093×10^{-4} YAE:4.17720×10^{-6} YAF:-1.52547×10^{-7} YAG:1.00136×10^{-9} YAOD:-2.74354×10^{-4} YAOE:-2.05378×10^{-5} YAOF:3.86108×10^{-7} YAOG:-1.04814×10^{-8} XAD:7.90990×10^{-5} XAE:1.59051×10^{-6} BC:-1.94677×10^{-2} BD:-8.78028×10^{-5} BE:7.74365×10^{-6} QC:6.58999×10^{-4} QD:7.68549×10^{-6} QE:-2.82293×10^{-7}
	d5 : 7.7
Image Surface	α5 : 16

TABLE 12

efy=4.95 efx=8.2

Diaphragm	ϕ 3.0
	d1 : 4.61
M1	α1 : 45 rdy:−26.05860 rdx:−231.38724 YAD:1.13086×10^{-4} YAE:3.51177×10^{-6} YAOD:6.95109×10^{-4} YAOE:-3.68896×10^{-5} XAD:-8.99603×10^{-4} XAE:5.89230×10^{-5} BC:-2.80934×10^{-2} BD:5.15443×10^{-3} BE:-3.44450×10^{-4} QC:-7.07468×10^{-4} QD:1.31488×10^{-4} QE:-1.05427×10^{-6}
	d2 : 10.77
M2	α2 : 45 rdy:−47.14360 rdx:14.09192 YAD:1.05855×10^{-5} YAE:-5.15419×10^{-8} YAOD:1.61859×10^{-4} YAOE:3.57701×10^{-7} BC:8.86211×10^{-3} BD:2.79229×10^{-4} BE:-1.51749×10^{-7} BOC:-8.51733×10^{-2} BOD:-1.33082×10^{-3} BOE:-1.67158×10^{-5}
	d3 : 19.85
M3	α3 : 37.5 rdy:−48.71404 rdx:−20.18595 YAD:-3.39048×10^{-6} YAE:-3.93960×10^{-10} YAOD:3.51027×10^{-5} YAOE:6.87239×10^{-7} BC:-7.23384×10^{-4} BD:1.68686×10^{-6} BE:-2.02686×10^{-8} BOC:-1.28481×10^{-3} BOD:1.87548×10^{-5} BOE:7.68548×10^{-9}
	d4 : 32
M4	α4 : 30 rdy:−19.60674 rdx:−8.10187 YAD:-1.24501×10^{-4} YAE:4.20698×10^{-6} YAF:-1.53240×10^{-7} YAG:1.57661×10^{-9} YAOD:-2.99700×10^{-4} YAOE:-1.98046×10^{-5} YAOF:4.44908×10^{-7} YAOG:-6.01927×10^{-9} XAD:-4.36066×10^{-4} XAE:1.34309×10^{-5} BC:-1.84671×10^{-2} BD:5.84417×10^{-4} BE:-3.57662×10^{-5} QC:1.67513×10^{-4} QD:4.57392×10^{-5} QE:-1.83992×10^{-6}
	d5 : 7.67
Image Surface	α5 : 16

TABLE 13

efy=4.95 efx=4.95

Diaphragm	ϕ 3.2
	d1:3.00
M1	α 1:45 rds:−56.05448 rdx:−216.244 BC:-2.8969×10^{-4}
	d2 : 8.69
M2	α 2 : 45 rdy:−43.65798 rdx:38.709 YAD:-7.8390×10^{-6} YAOD:-1.4886×10^{-4} BC:1.9375×10^{-2} BD:-7.2563×10^{-6} BOC:-1.4554×10^{-1} BOD:-2.3041×10^{-3} BOE:1.4646×10^{-5}
	d3 : 22.42
M3	α 3 : 38.25 rdy:−37.19418 rdx:−15.512 YAD:3.4667×10^{-6} YAE:-9.7392×10^{-9} YAOD:6.0230×10^{-5} YAOE:1.1883×10^{-7} BC:-1.1697×10^{-3} BD:-5.5848×10^{-6} BE:3.1089×10^{-8} BOC:-1.3653×10^{-2} BOD:5.6768×10^{-6} BOE:7.0581×10^{-7}
	d4 : 21.20
M4	α 4 : 23 rdy:−13.61471 rdx:−6.689 YAD:-8.9706×10^{-5} YAE:-3.8937×10^{-6} YAF:1.7972×10^{-7} YAG:-4.6226×10^{-9} YAOD:-6.2867×10^{-4} YAOE:-1.8252×10^{-5} YAOF:-3.0516×10^{-7} YAOG:8.6097×10^{-9} BC:-7.6081×10^{-3} BD:-2.0279×10^{-5} BE:2.0871×10^{-6} BF:-5.3320×10^{-8} BOC:-1.0168×10^{-2} BOD:-3.3021×10^{-4} BOE:9.9320×10^{-6} BOF:-1.9129×10^{-7}
	d5 : 6.00
Image Surface	α 5 : 2.7

According to the present embodiment, the mirrors with curved-axis X toric surfaces and curved-axis Y toric surfaces, each of which has a high-level capability of aberration correction, are eccentrically arranged. Therefore, it is possible to guide light fluxes to an image surface without blocking the same, thereby allowing excellent image formation.

This allows the optical performance to be enhanced, as compared with the two-mirror configuration. Furthermore, because a condition that the F value is not higher than 3.5 is satisfied, the foregoing configuration can be applied to a system with requirements of high resolution and high sensitivity. Aberration diagrams of the examples shown in Tables 3 to 13 are shown in FIGS. 6 to 16.

Incidentally, in the present embodiment, the shape of the mirror surface is that defined by the formulae (1) through (5), or that defined by the formulae (6) through (10), but it may be a surface of a form defined by different formulae as long as it is a similar surface.

Furthermore, the present embodiment is explained by taking as an example the reflective optical device having four reflection surfaces, but the device may have three reflection surfaces. In the case where the reflection surfaces are not less than three, the optical performance can be improved as compared with the case of the two-surface configuration. Therefore, it can be applied to a system with requirements of high resolution and high sensitivity, and the resolution necessary for image formation in the infrared range (wavelength: 3μm to 5μm, or 8μm to 12μm) can be obtained.

To obtain such necessary resolution, it is necessary to decrease the F value to an extent such that the influence of diffraction decreases. This is possible in the case where the reflection surfaces are not less than three, as in the present embodiment. For instance, in the case where the wavelength is 10μm, the F value of 1.9 allows MTF of not less than 20% and 35 (1.P/mm) to be obtained, and the F value of 1.6 allows MTF of not less than 20% and 40 (1.P/mm) to be obtained. Thus, the configuration is applicable to an infrared imaging system with high-resolution and high-sensitivity requirements.

<u>Third Embodiment</u>

FIG. 17 is a view illustrating a configuration of an imaging device according to a third embodiment of the present invention. The imaging device shown in the figure includes an aperture 11, a first mirror 12, a second mirror 13, and a two-dimensional imaging element 14. The

arrangement of the first and second mirrors 12 and 13 and their surface forms are identical to those in the first embodiment. The aperture 11 functions as an aperture diaphragm that transmits light in the wavelength range necessary for image formation, thereby limiting a light beam diameter, and further has a function of preventing dust from entering the optical system.

Light fluxes from an object are limited by the aperture 11 disposed at the diaphragm position, reflected by the mirrors 12 and 13, and then, projected to the two-dimensional imaging element 14, where an image is formed. Then, an image converted into electric signals by the two-dimensional imaging element 14 is outputted (arrow a).

According to the present embodiment, the imaging device includes the reflective optical device according to the first embodiment and a detecting means that converts light intensity into an electric signal, and further, uses a two-dimensional imaging element as the detecting means. Therefore, it is possible to obtain wide-angle, high-resolution image signals. Furthermore, in the case where a two-dimensional imaging element with sensitivity to infrared rays (wavelength: 3μm to 5μm, or 8μm to 12μm) is used, it is possible to image infrared images.

Fourth Embodiment

FIG. 18 is a view illustrating a configuration of a multi-wavelength imaging device according to a fourth embodiment of the present invention. Reference numerals 11 to 13 denote the same members as those in the third embodiment. In the fourth embodiment, the device further includes a wavelength selecting filter 15, an infrared imaging element 16, and a visible imaging element 17. The wavelength selecting filter 15 transmits only infrared rays (wavelength: 3μm to 5μm, or 8μm to 12μm) and reflects visible rays (wavelength: 400μm to 750μm). The infrared imaging element 16 has sensitivity with respect to infrared rays, while the visible imaging element 17 has sensitivity with respect to visible rays.

Light fluxes in two wavelength ranges (visible and infrared) from an object are limited by the aperture 11 disposed at a diaphragm position, and converged by the two mirrors 12 and 13. Light fluxes in the infrared range pass through the wavelength selecting filter 15, and are projected to the two-dimensional imaging element 16, from which an image converted into electric signals is outputted (arrow b).

Light fluxes in the visible range reflected by the wavelength

selecting filter 15 are projected to the two-dimensional imaging element 17, from which an image converted into electric signals is outputted (arrow c). Since the light fluxes in the two wavelength ranges are imaged by an optical system composed of mirrors that never cause color aberration exclusively, identical optical performance can be obtained.

Furthermore, since the infrared imaging element and the visible imaging element are used as imaging elements, both the image formation in the visible range that is suitable for image formation in the daytime and the image formation in the infrared range that is suitable for image formation at night can be carried out. In other words, according to the present embodiment, since in the reflective optical device the optical system for converging light fluxes is composed of reflection surfaces, the device can be used with respect to light fluxes in any wavelength range, from the infrared range (wavelength: 3μm to 5μm, or 8μm to 12μm), the visible range (wavelength: 400μm to 750μm), to the ultraviolet range (wavelength: 200nm to 400nm). By combining the same with a detecting means with sensitivity to a plurality of wavelength ranges, it is possible to form images in a plurality of wavelength ranges at the same time by use of one optical system.

<u>Fifth Embodiment</u>

FIG. 19 is a view illustrating a configuration of a multi-wavelength imaging device according to a fifth embodiment of the present invention. In the foregoing figure, the reference numerals 11 to 13 denote the same members as those in the third embodiment. In the present embodiment, the device further includes a multi-wavelength imaging element 18 that has sensitivity with respect to infrared rays and visible rays both.

Light fluxes in two wavelength ranges (visible and infrared) from an object are limited by the aperture 11 disposed at a diaphragm position. Then, the light fluxes are brought into focus by the two mirrors 12 and 13 on the multi-wavelength imaging element 18.

The light fluxes in two wavelength ranges are projected to an optical system composed only of mirrors that cause no chromatic aberration at all to form images. Therefore, identical optical performance can be obtained. Besides, the multi-wavelength imaging element 18 is configured so that regions with sensitivity to rays in the visible range and regions with sensitivity to rays in the infrared range are dispersedly arranged in the same imaging plane. Therefore, images in the two wavelength ranges can

be converted into two types of electric signals, that is, infrared-range image signals (arrow d) and visible-range image signals (arrow e).

In other words, according to the present embodiment, images in a plurality of wavelength ranges can be simultaneously formed with one optical system and one imaging element.

Sixth Embodiment

FIG. 20 is a view illustrating a configuration of a vehicle-mounted monitor according to a sixth embodiment of the present invention. The vehicle-mounted monitor shown in the drawing includes a multi-wavelength imaging device 19 according to the fourth embodiment and a display device 20.

Images in two wavelength ranges (visible range and infrared range) outputted from the multi-wavelength imaging device 19 are displayed by the display device 20, and the driver is allowed to get information as needed. For instance, when it is light outside in the daytime, information is obtained mainly from images with visible light, and at night, important information as to positions of a pedestrian or a car, etc. is obtained from images with infrared rays. In other words, the present embodiment allows position information concerning cars driving ahead, pedestrians, etc. to be obtained precisely at all times, irrespective of the daytime or night.

Seventh Embodiment

FIG. 21 is a perspective view illustrating a configuration of a reflective optical device according to a seventh embodiment of the present invention. The reflective optical device 21 shown in the drawing is configured as follows: a front optical member 22 and a rear optical member 23, each in a shell-like shape, are opposed to each other at a border plane 25 and bonded integrally so that a hollow space is formed therein. An aperture 24 is provided in the front optical member 23, through which light fluxes for image formation enter therein.

FIG. 22 is a cross-sectional view of the reflective optical device 21 show in FIG. 21 taken in a direction perpendicular to the border plane 25. The light fluxes having passed through the aperture 24 for image formation, travel along an optical axis 26. Thereafter the light fluxes are reflected by a reflection surface 27 formed on an internal surface of the shell-shaped rear optical member 23, and a reflection surface 28 formed on an internal surface of the shell-shaped front optical member 22. Finally, the light fluxes are projected to a photosensitive member 29 with photosensitivity, whereby an

image is formed.

Among the reflection surfaces 27 and 28, at least one is a free-form surface, and an excellent image can be obtained by this eccentric optical system. As the free-form surface, a curved-axis Y toric surface shown in FIG. 2 (the formulae (1) through (5)) or a curved-axis X toric surface (the formulae (6) through (10)) can be used, for instance.

By providing such a free-form surface as the reflection surface on the internal surface of the shell-shaped optical member, the aberration-correcting capability of an eccentric optical system can be obtained, and hence, a configuration of an optical system with an optical path that conventionally has not been available is obtained. Furthermore, the blocking by the reflection surface itself is avoided, and an optical system with an increased angle of vision can be obtained. In other words, by integrally providing a plurality of shell-shaped optical members so that they are opposed to each other as in the present embodiment, it is possible to provide a reflective optical device that is cost-reduced and miniaturized compatibly, and has an enhance aberration correcting capability and an increased angle of view.

FIG. 23 is a cross-sectional view of the reflective optical device shown in FIG. 21 taken in a direction perpendicular to the border plane 25. The reflective optical device shown in this drawing is provided with an aperture 30 for causing image formation to occur outside the reflective optical device 21.

The light fluxes having passed through the aperture 24 for image formation travel along the optical axis 26. Thereafter the light fluxes are reflected by the reflection surface 27 formed on the internal surface of the shell-shaped rear optical member 23, and the reflection surface 28 formed on the internal surface of the shell-shaped front optical member 22. Finally, the light fluxes are projected to a photosensitive member 29 with photosensitivity that is provided outside the aperture 30 for image formation, whereby an image is formed.

Incidentally, in the present embodiment, the form of the reflection surface is that defined by the formulae (1) through (5) or that defined by the formulae (6) through (10), but it may be a surface of a form defined by different formulae as long as it is a similar surface.

<u>Eighth Embodiment</u>

FIG. 24 illustrates a reflective optical device in which optical

members are formed with resin moldings and metallic thin films are formed on regions of reflection surfaces. A front optical member 22 in a shell-like shape is formed in the following manner: a resin material is formed into a desired shape by hot pressing or injection molding, and thereafter, a metallic thin film 31 is formed in a region of a reflection surface by vacuum deposition or plating.

Likewise, a rear optical member 23 in a shell-like shape is formed in the following manner: a resin material is formed into a desired shape by hot pressing or injection molding, and thereafter, a metallic thin film 32 is formed in a region of a reflection surface by vacuum deposition or plating. This configuration allows the substantially whole structure to be formed with resin moldings, and metallic films to be formed only on the reflection surfaces. Therefore, it is possible to obtain a low-cost reflective optical device.

As a material used for forming a metallic thin film, a material may be selected that is suitable for wavelengths of light fluxes from a subject as a target to be imaged: for instance, aluminum, gold, silver, copper or zinc. Aluminum has an excellent reflectance, while being inexpensive. Gold is superior in environmental resistance, and has an excellent reflectance as to light fluxes in the infrared range. Silver is industrially applicable from the viewpoint of cost, and has an excellent reflectance. Copper has an excellent reflectance as to light fluxes in the infrared range, while being inexpensive. Zinc has a relatively excellent reflectance as to light fluxes in the infrared range, while being inexpensive.

Incidentally, a reflection surface on which a metallic thin film is formed by using aluminum, silver, copper, zinc, etc. tends to have a reflectance decreased due to oxidation. Therefore, it is desirable that SiO_2 or the like is laminated on the metallic thin film.

Ninth Embodiment

FIG. 25 illustrates a reflective optical device in which an optical member is made of a metal. On an internal surface of a front optical member 22 in a shell-like shape formed with a metal, a region 33 equivalent to a reflection region is formed. Likewise, on an internal surface of a rear optical member 23 in a shell-like shape formed with a metal, a region 34 equivalent to a reflection region is formed. It is possible to form the reflection surfaces 33 and 34 simultaneously when the optical members 22 and 23 are formed by press molding or die casting, respectively.

Furthermore, the reflection surfaces can be formed using cutting tools after the molding or casting.

As a material used for forming the optical member, a material may be selected that is suitable for wavelengths of light fluxes from a subject as a target to be imaged: for instance, aluminum, gold, silver, copper or zinc. Aluminum has excellent processability and reflectance, while being inexpensive. Gold is superior in environmental resistance, and has an excellent reflectance as to light fluxes in the infrared range. Silver is industrially applicable from the viewpoint of cost, and has an excellent reflectance. Copper has excellent processability and reflectance as to light fluxes in the infrared range, while being inexpensive. Zinc has excellent processability, while being inexpensive.

Incidentally, a reflection surface formed on an optical member formed by using aluminum, silver, copper, zinc, etc. tends to have a reflectance decreased due to oxidation. Therefore, it is desirable that SiO_2 or the like is laminated on the metallic member.

Furthermore, in the case where metallic thin films 35 and 36 are formed on reflection-surface-equivalent regions on surfaces of the shell-shaped optical members 22 and 23 made of metals, as illustrated in FIG. 26, the optical characteristics are further improved.

Generally, as compared with a metallic material forming a structure, a metallic material used in vacuum deposition or plating has a higher impurity, and a metallic thin film formed with such a metallic material has a higher reflectance. As a material used for forming a metallic thin film, a material may be selected that is suitable for wavelengths of light fluxes from a subject as a target to be imaged: for instance, aluminum, gold, silver, copper or zinc. Aluminum has an excellent reflectance, while being inexpensive. Gold is superior in environmental resistance, and has an excellent reflectance as to light fluxes in the infrared range. Silver is industrially applicable from the viewpoint of cost, and has an excellent reflectance. Copper has an excellent reflectance as to light fluxes in the infrared range, while being inexpensive. Zinc has a relatively excellent reflectance as to light fluxes in the infrared range, while being inexpensive.

Incidentally, a reflection surface on which a metallic thin film is formed by using aluminum, silver, copper, zinc, etc. tends to have a reflectance decreased due to oxidation. Therefore, it is desirable that SiO_2 or the like

is laminated on the metallic thin film.

Tenth Embodiment

FIG. 27 illustrates a reflective optical device in which a front optical member 22 and a rear optical member 23, each in a shell-like shape, are opposed to each other and provided integrally, and a window member 38 to allow light fluxes in a wavelength range necessary for image formation to pass therethrough is added to an aperture 24 provided on the front optical member 22.

The present embodiment allows necessary light fluxes to pass therethrough, and at the same time prevents dust and water droplets from entering from the external into the internal space of the hollow structure formed by integrally providing the front optical member 22 and the rear optical member 23.

The window member 38 preferably is formed with a material that allows light fluxes in a wavelength range necessary for image formation to pass therethrough, while blocking light fluxes in the other wavelength ranges. This causes unnecessary light fluxes in the unnecessary wavelength ranges not to enter the inside of the reflective optical device, whereby an image with an excellent contrast can be obtained.

In the case where germanium is used for forming the window member, it is possible to block light fluxes in the visible range while to transmit light fluxes in the infrared range. This enables the image formation by using light fluxes in the infrared range, which does not affect light fluxes in the visible range. Likewise, in the case where silicon is used for forming the window member, it is possible to block light fluxes in the visible range while to transmit light fluxes in the infrared range. This enables the image formation by using light fluxes in the infrared range, which does not affect light fluxes in the visible range. In the case where polyethylene is used for forming the window member, it is possible to transmit light fluxes in the visible range and in the infrared range both, thereby making the image formation by using light fluxes in the visible range and in the infrared range both. Likewise, in the case where ZnSe is used for forming the window member, it is possible to transmit light fluxes in the visible range and in the infrared range both, thereby making the image formation by using light fluxes in the visible range and in the infrared range both. Furthermore, the window member may be formed with a material other than the above, as required. For instance, CaF_2 or

BaF_2 may be used.

As illustrated in FIG. 27, the window member 38 is formed with flat plates. The structure in the flat-plate shape is easily processed at a low cost, and the adding of the same to the optical member is easy as well. The window member preferably is in a lens form and has a lens function. This makes it possible to also cause the window member to provide a part of the optical power contributing in the image formation, thereby enhancing the aberration correcting capability of the overall system, and further, improving the optical performance.

Eleventh Embodiment

FIG. 28 illustrates an imaging device in which, to a reflective optical device composed of a front optical member 22 and a rear optical member 23, each in a shell-like shape, an imaging element 39 is added, on the outside of an image-forming-use aperture 30 provided in the rear optical member 23. Examples of the imaging element 39 include a CCD element, a bolometer array element utilizing a heat-resistance converting function, and a pyrometer array element utilizing a heat-electromotive force converting function.

By adapting a CCD imaging element as the imaging element with sensitivity to the visible range, the image formation is enabled as to the visible range. By adapting a bolometer array element or a pyrometer array element as the imaging element with sensitivity to the infrared range, the image formation is enabled as to the infrared range. By utilizing an imaging element in which a photo diode array and either a bolometer array or a pyrometer array monolithically are provided, the image formation is enabled as to the visible range and the infrared range both.

Twelfth Embodiment

FIG. 29 illustrates an example in which an imaging device 40 according to the present invention is mounted on a vehicle 41, so as to be used as a vehicle-mounted monitor including a vehicle-mounted visual supporting device. A situation ahead of a vehicle 92 is imaged by an imaging device 70. By processing the image, it is possible to detect whether or not the vehicle is deviating from a traffic lane. Besides, by displaying the image on a display device (not shown) provided at a driving seat, it is possible to support human vision.

Furthermore, in the case where the imaging device utilizes an imaging element with sensitivity to the infrared range, it is possible to

image a situation at night that is not visible to human eyes. Furthermore, the imaging device may be mounted on a side or at a rear of the vehicle, thereby providing images as required according to various situations.

Thirteenth Embodiment

FIG. 30 is a perspective view illustrating a configuration of a reflective optical device according to a thirteenth embodiment of the present invention. A front optical member 43 and a rear optical member 44, each in a shell-like shape, are bonded to each other at a border plane 46, thereby being provided integrally, in a state in which their respective concave surfaces are opposed to each other. An aperture is provided in the front optical member 43, and a window member 45 is provided on the aperture on the object side (on the outside). Light fluxes used in image formation enter through the window member 45 and the aperture. The window member 45 has an optical property of preventing at least infrared rays in a specific wavelength range from transmitting therethrough, among the incident infrared rays. Since such a window member 45 is provided, it is possible not to admit light fluxes with unnecessary wavelengths into the reflective optical device. As a result, it is possible to obtain an image with an excellent contrast.

FIG. 31 is a cross-sectional view of the reflective optical device 42 show in FIG. 30 taken along a plane that includes the optical axes and is perpendicular to the border plane 46. The light fluxes having passed through the window member 45 for image formation, then, through the aperture 51, travel along an optical axis 47. Thereafter the light fluxes are reflected by a reflection surface 48 formed on an internal surface of the shell-shaped rear optical member 44, and a reflection surface 49 formed on an internal surface of the shell-shaped front optical member 43. Finally, the light fluxes are projected to a photosensitive member 50 with photosensitivity, whereby an image is formed.

Among the reflection surfaces 48 and 49, at least one is a free-form surface, and an excellent image can be obtained by this eccentric optical system. As the free-form surface, a curved-axis Y toric surface shown in FIG. 2 (the formulae (1) through (5)) or a curved-axis X toric surface (the formulae (6) through (10)) can be used, for instance.

By providing such a free-form surface as the reflection surface on the internal surface of the shell-shaped optical member, aberration correcting capability of an eccentric optical system can be obtained, and hence, a

configuration of an optical system with an optical path that conventionally has not been available is obtained. Furthermore, the blocking by the reflection surface itself is avoided, and an optical system with an increased angle of vision can be obtained. In other words, by integrally providing a plurality of shell-shaped optical members so that they are opposed to each other as in the present embodiment, it is possible to provide a reflective optical device that is cost-reduced and miniaturized at the same time compatibly and has an enhanced aberration correcting capability and an increased angle of view.

A reflective optical device shown in FIG. 32 is the reflective optical device 42 shown in FIG. 30, further provided with an aperture 52 for causing image formation to occur outside the reflective optical device 42. The light fluxes having passed through the window member 45 for image formation, and then, through the aperture 51, travel along an optical axis 47. Thereafter the light fluxes are reflected by a reflection surface 48 formed on an internal surface of the shell-shaped rear optical member 44, and a reflection surface 49 formed on an internal surface of the shell-shaped front optical member 43. Finally, the light fluxes are projected to a photosensitive member 50 with photosensitivity that is provided outside an aperture 52, whereby an image is formed.

Here, the window member 45 is composed of a multi-layer film formed with thin films made of a dielectric material with a low reflectance and thin films made of a dielectric material with a high reflectance that are alternately laminated on a transparent substrate. As a material to form a transparent substrate, a glass material, a resin material, CaF_2, BaF_2, or ZnSe is used. Furthermore, the window member 45 may be made of a glass material absorbing infrared rays, or may be made of a resin material absorbing infrared rays.

The window member 45 preferably is formed with flat plates. The structure in the flat-plate shape is easily processed at a low cost, and the adding of the same to the optical member is easy as well. The window member 45 more preferably is in a lens form and has a lens function. This makes it possible to also cause the window member 45 to provide a part of the optical power contributing in the image formation, thereby enhancing the aberration correcting capability of the overall system, and further, improving the optical performance.

In the case where the photosensitive member 50 is sensitive to light

fluxes in the visible and far infrared ranges both, the range of wavelengths of infrared rays prevented from transmitting by the window member preferably is limited to a range of near infrared rays. By so doing, it is possible to suppress the incidence of unnecessary components of light to members having sensitivity to the respective wavelength ranges. As to the wavelength range of the near-infrared rays, a range of 700nm to 1100nm is preferable. A transmittance of light fluxes in the near infrared range, which are unnecessary light, preferably is not more than 10%. This allows the image formation to be conducted excellently. In other words, it is possible to form images with desirable color tones, without affecting spectral wavelength components in the visible range. At the same time, this does not affect spectral wavelength components in the far infrared range, thereby making it possible to form a thermal image.

FIG. 33 is a cross-sectional view of an imaging device 53 provided with an imaging element 54 outside the aperture 52. Examples of the imaging element 54 include a CCD element, a bolometer array element utilizing a heat-resistance converting function, and a pyrometer array element utilizing a heat-electromotive force converting function.

By adapting a CCD imaging element as the imaging element 54, the image formation is enabled as to the visible range. The window 45 in this case preferably has a property of not transmitting infrared rays. By adapting a bolometer array element or a pyrometer array element as the imaging element 54, the image formation is enabled as to the infrared range. By using an imaging element 54 in which a photo diode array and either a bolometer array or a pyrometer array are provided monolithically, the image formation is enabled as to the visible range and the infrared range both. The window member 45 in this case preferably has a property of not transmitting near infrared rays.

Incidentally, in the present embodiment, the form of the reflection surface is that defined by the formulae (1) through (5) or that defined by the formulae (6) through (10), but it may be a surface of a form defined by different formulae as long as it is a similar surface.

Besides, the imaging element 54 may be provided inside the reflective imaging device 53. Moreover, a plurality of reflection surfaces may be provided on each of the optical members 43 and 44, and in this case it is possible to further enhance the aberration correcting capability.

Fourteenth Embodiment

FIG. 34 is a cross-sectional view of a reflective optical device according to a fourteenth embodiment. In a region of an internal surface of the front optical member 43, which region is to constitute a reflection surface, a film 55 is provided that has an optical property of not reflecting at least infrared rays in a specific waveform range among the infrared rays incident thereto. Likewise, in a region of an internal surface of the rear optical member 44, which region is to constitute a reflection surface, a film 56 is provided that has an optical property of not reflecting at least infrared rays in a specific waveform range among the infrared rays incident thereto. The films 55 and 56 are formed by vacuum deposition or coating.

This configuration allows only spectrum components necessary for image formation, among the light fluxes having entered through the aperture 51, to contribute to the image formation, thereby avoiding the light fluxes in an unnecessary wavelength range. As a result, an image with an excellent contrast can be obtained. Furthermore, it is possible to reduce the costs, since the device is composed of a decreased number of component parts.

Among the reflection surfaces on which the films 55 and 56 are formed, at least one is a free-form surface, and an excellent image can be obtained by this eccentric optical system. As the free-form surface, a curved-axis Y toric surface shown in FIG. 2 (the formulae (1) through (5)) or a curved-axis X toric surface (the formulae (6) through (10)) can be used, for instance.

By providing such a free-form surface as defined by the foregoing formulae on the internal surface of each of the optical members 43 and 44 as the reflection surface, aberration-correcting capability of an eccentric optical system can be obtained, and hence, a configuration of an optical system with an optical path that conventionally has not been available is obtained. Furthermore, the blocking by the reflection surface itself is avoided, and an optical system with an increased angle of vision can be obtained. In other words, by integrally providing a plurality of shell-shaped optical members so that they are opposed to each other as in the present embodiment, it is possible to provide a reflective optical device that is cost-reduced and miniaturized at the same time compatibly and has an enhanced aberration correcting capability and an increased angle of view.

FIG. 35 is a cross-sectional view of a reflective optical device provided with an aperture 52. The configuration other than the aperture

52 and a photosensitive member 50 is the same as that of the reflective optical device shown in FIG. 34. The aperture 52 is intended to cause images to be formed outside the reflective optical device. Light fluxes having entered through an aperture 51 for image formation are reflected by a reflection surface formed on an internal surface of the shell-shaped rear optical member 44, and a reflection surface formed on an internal surface of the shell-shaped front optical member 43. Finally, the light fluxes are projected to the photosensitive member 50 with photosensitivity that is provided outside the aperture 52, whereby an image is formed.

To form the films 55 and 56 by vacuum deposition, a multi-layer film is formed on each of the internal surfaces of the optical members 43 and 44 by alternately laminating thin films made of a dielectric material with a low reflectance and thin films made of a dielectric material with a high reflectance by vapor deposition. To form the same by coating, a material that transmits light fluxes in the visible range and absorbs light fluxes in the infrared range, such as an acrylic resin, is coated on a reflection surface formed beforehand on each of the internal surfaces of the optical members 43 and 44.

The films 55 and 56 are configured so as to have an optical property of not reflecting light fluxes in a range of wavelengths longer than those in the visible range, and preferably, an optical property of not reflecting light fluxes in a range of wavelengths longer than 700nm. This allows the light fluxes used in image formation to be composed of only spectrum components in the visible range. Therefore, images with desirable color tones can be formed.

In the case where the photosensitive member 50 having photosensitivity is sensitive to light fluxes in the visible and far infrared ranges both, the range of wavelengths of infrared rays prevented from being reflected by the films preferably is limited to a range of near infrared rays. By so doing, it is possible to suppress the incidence of unnecessary components of light to members having sensitivity to the respective wavelength ranges. As to the wavelength range of the near-infrared rays, a range of 700nm to 1100nm is preferable. A reflectance of light fluxes in the near infrared range, which are unnecessary light, more preferably is not more than 10%. This allows the image formation to be conducted excellently. In other words, it is possible to form images with desirable color tones, without affecting spectral wavelength components in the visible

range. At the same time, this does not affect spectral wavelength components in the far infrared range, thereby making it possible to form a thermal image.

A reflective optical device 57 shown in FIG. 36 differs from the reflective optical device shown in FIG. 35 in the aspect that an imaging element 54 is attached to the outside of the aperture 52. Adaptable as the imaging element 54 is a CCD element, a bolometer array element utilizing a heat-resistance converting function, a pyrometer array element utilizing a heat-electromotive force converting function, or the like.

By adapting a CCD imaging element as the imaging element 54, the image formation is enabled as to the visible range. In this case, the reflection surface preferably has a property of not reflecting infrared rays. By adapting a bolometer array element or a pyrometer array element as the imaging element 54, the image formation is enabled as to the infrared range. By using an imaging element 54 in which a photo diode array and either a bolometer array or a pyrometer array are provided monolithically, the image formation is enabled as to the visible range and the infrared range both. The reflection surface in this case preferably has a property of not reflecting near infrared rays.

Incidentally, in the present embodiment, the form of the reflection surface is that defined by the formulae (1) through (5) or that defined by the formulae (6) through (10), but it may be a surface in a form defined by different formulae as long as it is a similar surface.

Besides, the imaging element 54 may be provided inside the shell-shaped reflective imaging device 57. Moreover, a plurality of reflection surfaces may be provided on each of the optical members 43 and 44, and in this case it is possible to further enhance the aberration correcting capability.

<u>Sixteenth Embodiment</u>

FIG. 37 is a perspective view illustrating a configuration of a reflective solid-state optical device of the present invention. A diaphragm 81 is provided on a light-incident side of the reflective solid-state optical device 80. FIG. 38 is a cross-sectional view of the same taken along a plane containing an optical axis 47. The reflective solid-state optical device 80 is configured so as to be in a solid state, with a solid optical medium that has an optical property of not transmitting at least infrared rays in a specific wavelength range. On a surface of the optical medium, surfaces 91 and 92

are formed, at least one of which is a free-form surface. On the surfaces 91 and 92, reflection films 93 and 94 are formed. Thus, an optical system is configured in one piece.

Light fluxes having entered through the diaphragm 81 travel along the optical axis 47 through the solid optical medium. Then, the light fluxes are reflected by the reflection surface composed of the reflection film 94 and the free-form surface 92, as well as by the reflection surface composed of the reflection film 93 and the free-form surface 91, and are projected to the photosensitive member 50 with photosensitivity, where an image is formed.

By so doing, light fluxes in an unnecessary wavelength range by no means are directed to the photosensitive member 50, and an image with an excellent contrast can be obtained. Furthermore, it is possible to reduce the costs, since the device is composed of a decreased number of component parts.

At least one of the surfaces 91 and 92 is a free-form surface, and an excellent image can be obtained by this eccentric optical system. As the free-form surface, a curved-axis Y toric surface shown in FIG. 2 (the formulae (1) through (5)) or a curved-axis X toric surface (the formulae (6) through (10)) can be used, for instance.

By providing such a free-form surface as defined by the foregoing formulae on the solid optical medium surfaces as the reflection surface, aberration-correcting capability of an eccentric optical system can be obtained, and hence, a configuration of an optical system with an optical path that conventionally has not been available is obtained. Furthermore, the blocking by the reflection surface itself is avoided, and an optical system with an increased angle of vision can be obtained. In other words, by integrally providing a plurality of reflection surfaces on solid optical medium surfaces as in the present embodiment, it is possible to provide a reflective solid-state optical device that is cost-reduced and miniaturized at the same time compatibly and has an enhanced aberration correcting capability and an increased angle of view.

The optical medium is prepared so as to have an optical property of not transmitting light fluxes in a range of wavelengths longer than those in the visible range, and preferably, an optical property of not transmitting light fluxes in a range of wavelengths longer than 700nm. This allows the light fluxes used in image formation are composed of only spectrum components in the visible range. Therefore, images with desirable color

tones can be formed.

In the case where the photosensitive member 50 having photosensitivity is sensitive to light fluxes in the visible and far infrared ranges both, the range of wavelengths of infrared rays not transmitted by the optical medium preferably is limited to a range of near infrared rays. By so doing, it is possible to suppress the incidence of unnecessary components of light to members having sensitivity to the respective wavelength ranges. As to the wavelength range of the near-infrared rays, a range of 700nm to 1100nm is preferable. A transmittance of light fluxes in the near infrared range, which are unnecessary light, more preferably is not more than 10%. This allows the image formation to be conducted excellently. In other words, it is possible to form images with desirable color tones, without affecting spectral wavelength components in the visible range. At the same time, this does not affect spectral wavelength components in the far infrared range, thereby making it possible to form a thermal image.

A reflective solid-state optical device shown in FIG. 39 differs from the reflective optical device shown in FIG. 38 in the aspect that an imaging element 59 is provided in place of the photosensitive member 50 of the reflective solid-state optical device shown in FIG. 38. Adaptable as the imaging element 59 is a CCD element, a bolometer array element utilizing a heat-resistance converting function, a pyrometer array element utilizing a heat-electromotive force converting function, or the like. By adapting a CCD imaging element as the imaging element 59, the image formation is enabled as to the visible range. In this case, the optical medium preferably has a property of not transmitting infrared rays.

By adapting a bolometer array element or a pyrometer array element as the imaging element 59, the image formation is enabled as to the infrared range. By using an imaging element in which a photo diode array and either a bolometer array or a pyrometer array are provided monolithically, the image formation is enabled as to the visible range and the infrared range both. The optical medium in this case preferably has a property of not transmitting near infrared rays.

Incidentally, in the present embodiment, the form of the reflection surface is that defined by the formulae (1) through (5) or that defined by the formulae (6) through (10), but it may be a surface of a form defined by different formulae as long as it is a similar surface.

Seventeenth Embodiment

FIG. 40 illustrates a state in which an imaging device 110 according to the present invention is installed in a video camera device 111. The imaging device 110 is configured so that a reflective optical device or reflective solid-state optical device projects an image of a subject to an imaging element, which therefore outputs an image signal. The image signal, though not shown in the drawing, is recorded in a recording medium by electric circuits and mechanisms. Since the imaging device is small and low-cost while provides high contrast, this is effective for miniaturization, cost reduction, and enhancement of the performance, of the video camera device.

Eighteenth Embodiment

FIG. 29 illustrates a state in which the imaging device 110 according to the present invention is installed in a vehicle 41 so as to compose a vehicle-mounted visual supporting device. A situation ahead of the vehicle 41 is imaged by the imaging device 110. The image obtained is processed by an image processing device (not shown) provided in a vehicle visual supporting device. This allows deviation of the vehicle from a traffic lane, a vehicle driving ahead, an obstacle ahead, etc. to be detected.

Besides, by displaying the image on a display device (not shown) provided at a driving seat, it is possible to support human vision. Furthermore, in the case where the imaging device utilizes an imaging element with sensitivity to light fluxes in the infrared range, it is possible to image a situation that is not visible to human eyes. Furthermore, the imaging device may be mounted on a side or at a rear of the vehicle, thereby providing images as required according to various situations. Furthermore, since the imaging device is small and cost-reduced while providing a high contrast, it allows a degree of freedom to be obtained in installing the imaging device, thereby allowing a high-performance vehicle-mounted visual supporting device to be provided.

INDUSTRIAL APPLICABILITY

As described above, a device provided by the present invention can be used as a reflective optical device or a reflective solid-state optical device that provides an increased angle of vision and enhanced optical performance, and is miniaturized and cost-reduced at the same time compatibly, and also as a vehicle-mounted monitor such as an imaging device, a video camera

device, or a vehicle-mounted visual supporting device, utilizing the above.

CLAIMS

1. A reflective optical device, comprising two non-axisymmetric reflection surfaces for bringing light fluxes from an object into focus on an image surface, the two non-axisymmetric reflection surfaces being a first reflection surface and a second reflection surface, wherein:

the first and second reflection surfaces are disposed in this order in a direction in which the light fluxes travel, and are arranged eccentrically; and

each of the first and second reflection surfaces is concave in a cross-sectional shape taken along a plane containing a center of the image surface and vertices of the reflection surfaces.

2. The reflective optical device according to claim 1, further comprising a diaphragm for limiting light fluxes, the diaphragm being disposed between the first reflection surface and the object.

3. The reflective optical device according to claim 2, wherein a relationship expressed as below is satisfied:

$$0.3 < d1/efy < 1.5$$

where d1 represents a distance between a center of the diaphragm and the vertex of the first reflection surface, and efy represents a focal length in a plane containing the center of the image surface and the vertices of the first and second reflection surfaces.

4. The reflective optical device according to claim 2, wherein a relationship expressed as below is satisfied:

$$1.0 < d2/efy < 4.0$$

where d2 represents a distance between the vertex of the first reflection surface and the vertex of the second reflection surface, and efy represents a focal length in a plane containing the center of the image surface and the vertices of the first and second reflection surfaces.

5. The reflective optical device according to claim 1, wherein the first reflection surface is concave in a cross-sectional shape taken in a direction perpendicular to a plane containing the center of the image surface and the vertices of the first and second reflection surfaces.

6. The reflective optical device according to claim 1, wherein the second reflection surface is concave in a cross-sectional shape taken in a direction perpendicular to a plane containing the center of the image surface and the vertices of the first and second reflection surfaces.

7. The reflective optical device according to claim 1, wherein each of the first and second reflection surfaces is a free-form surface that does not have a rotational axis.

8. The reflective optical device according to claim 7, wherein the free-form surface is either a curved-axis Y toric surface or a curved-axis X toric surface, each of which is defined by a function f(X,Y) in a rectangular coordinate system (X, Y) in which the X direction is a direction perpendicular to a plane containing the center of the image surface and the vertices of the reflection surfaces and the Y direction is a direction of a tangent line at a vertex, the tangent line being contained in the plane,

the curved-axis Y toric surface being such that a line obtained by connecting centers of radii of curvature of X-direction cross sections at respective Y coordinates is a curved line,

the curved-axis X toric surface being such that a line obtained by connecting centers of radii of curvature of Y-direction cross sections at respective X coordinates is a curved line.

9. The reflective optical device according to claim 8, wherein the first reflection surface is a curved-axis Y toric surface or a curved-axis X toric surface, the curved axis-Y toric surface being such that a Y-direction cross section of the first reflection surface containing the vertex thereof is asymmetric with respect to a normal line at the vertex thereof, and a curved line connecting the centers of radii of curvature of the X-direction cross sections.

10. The reflective optical device according to claim 8, wherein the second reflection surface is a curved-axis Y toric surface or a curved-axis X toric surface, the curved axis Y toric surface being such that a Y-direction cross section of the first reflection surface containing the vertex thereof is asymmetric with respect to a normal line at the vertex thereof and a curved

line connecting the centers of radii of curvature of the X-direction cross sections.

11. A reflective optical device, comprising at least three reflection surfaces for bringing light fluxes from an object into focus on an image surface, wherein:

the reflection surfaces are arranged eccentrically;

an F value in a plane containing vertices of the respective reflection surfaces is less than 3.5; and

among the reflection surfaces, the two reflection surfaces on the object side are given as a first reflection surface and a second reflection surface, respectively, in an order from the object side in a direction in which the light fluxes travel, and each of the first and second reflection surfaces is concave in a cross-sectional shape taken along the plane.

12. A reflective optical device comprising at least three reflection surfaces for bringing light fluxes from an object into focus on an image surface, wherein:

the reflection surfaces are arranged eccentrically; and

an F value in a plane containing vertices of the respective reflection surfaces is less than 1.9.

13. The reflective optical device according to claim 12, wherein the F value is less than 1.6.

14. The reflective optical device according to claim 12, wherein, among the reflection surfaces, the two reflection surfaces on the object side are given as a first reflection surface and a second reflection surface, respectively, in an order from the object side in a direction in which the light fluxes travel, and each of the first and second reflection surfaces is concave in a cross-sectional shape taken along the plane.

15. A reflective optical device comprising at least three reflection surfaces for bringing light fluxes from an object into focus on an image surface, wherein:

the reflection surfaces are arranged eccentrically;

among the reflection surfaces, the reflection surface placed second

from the object side in a direction in which the light fluxes travel is given as a second reflection surface, and the second reflection surface is concave in a cross-sectional shape taken in the vicinity of its vertex along a plane containing vertices of the reflection surfaces, and is convex in a cross-sectional shape taken in a direction perpendicular to the plane.

16. The reflective optical device according to any one of claims 11, 12, and15, wherein the at least three reflection surfaces are non-axisymmetric surfaces.

17. The reflective optical device according to any one of claims 11, 12, and 15, wherein the reflection surfaces are four surfaces that are a first surface, a second surface, a third surface, and a fourth surface in an order from the object side in a direction in which the light fluxes travel.

18. The reflective optical device according to claim 17, wherein a relationship expressed as below is satisfied:

$$26 < \alpha 3 < 56$$

where $\alpha 3$ represents an angle (deg) formed between a normal line of the third reflection surface at its vertex and an optical axis extended from the vertex of the third reflection surface to a vertex of the fourth reflection surface.

19. The reflective optical device according to claim 17, further comprising a diaphragm for limiting the light fluxes, the diaphragm being disposed between the first reflection surface and the object.

20. The reflective optical device according to claim 19, wherein a relationship expressed as below is satisfied:

$$0.3 < d1/efy < 1.5$$

where d1 represents a distance between a center of the diaphragm and a vertex of the first reflection surface, and efy represents a focal length in the plane containing the vertices of the reflection surfaces.

21. The reflective optical device according to claim 19, wherein a relationship expressed as below is satisfied:

$$0.6 < d1/efy < 1.0$$

where d1 represents a distance between a center of the diaphragm and a vertex of the first reflection surface, and efy represents a focal length in the plane containing the vertices of the reflection surfaces.

22. The reflective optical device according to claim 19, wherein a relationship expressed as below is satisfied:

$$0.3 < d2/d4 < 1.0$$

where d2 represents a distance between a vertex of the first reflection surface and a vertex of the second reflection surface, and d4 represents a distance between a vertex of the third reflection surface and a vertex of the fourth reflection surface.

23. The reflective optical device according to claim 19, wherein a relationship expressed as below is satisfied:

$$2.6 < d4/efy < 7.5$$

where d4 represents a distance between a vertex of the third reflection surface and a vertex of the fourth reflection surface, and efy represents a focal length in the plane containing the vertices of the reflection surfaces.

24. The reflective optical device according to claim 19, wherein a relationship expressed as below is satisfied:

$$3.5 < d4/efy < 6.5$$

where d4 represents a distance between a vertex of the third reflection surface and a vertex of the fourth reflection surface, and efy represents a focal length in the plane containing the vertices of the reflection surfaces.

25. The reflective optical device according to claim 19, wherein a relationship expressed as below is satisfied:

$$0.5 < d5/efy < 2.0$$

where d5 represents a distance from a vertex of the fourth reflection surface to a center of an image surface, and efy represents a focal length in the plane containing the vertices of the reflection surfaces.

26. The reflective optical device according to claim 17, wherein each of the four reflection surfaces is concave in a cross-sectional shape taken along the plane containing the vertices of the reflection surfaces.

27. The reflective optical device according to claim 17, wherein, among the reflection surfaces, the first reflection surface is concave in a cross-sectional shape taken in a direction perpendicular to the plane containing the vertices of the reflection surfaces.

28. The reflective optical device according to claim 17, wherein, among the reflection surfaces, the third reflection surface is concave in a cross-sectional shape taken in a direction perpendicular to the plane containing the vertices of the reflection surfaces.

29. The reflective optical device according to claim 17, wherein, among the reflection surfaces, the fourth reflection surface is concave in a cross-sectional shape taken in a direction perpendicular to the plane containing the vertices of the reflection surfaces.

30. The reflective optical device according to claim 17, wherein the fourth reflection surface is a free-form surface that is in a non-axisymmetric form and that does not have a rotational axis.

31. The reflective optical device according to claim 17, wherein the fourth reflection surface is a free-form surface, and the free form surface is either a curved-axis Y toric surface or a curved-axis X toric surface, each of which is defined by a function f(X,Y) in a rectangular coordinate system (X, Y) in which the X direction is a direction perpendicular to a plane containing the center of the image surface and the vertices of the reflection surfaces and the Y direction is a direction of a tangent line at a vertex, the tangent line being contained in the foregoing plane,

the curved-axis Y toric surface being such that a line obtained by connecting centers of radii of curvature of the X-direction cross sections at respective Y coordinates is a curved line,

the curved-axis X toric surface being such that a line obtained by connecting centers of radii of curvature of the Y-direction cross sections at respective X coordinates is a curved line.

32. An imaging device, comprising:

the reflective optical device according to any one of claims 1, 11, 12, and 15; and

a detecting means that converts a light intensity into an electric signal.

33. The imaging device according to claim 32, wherein the detecting means is a two-dimensional imaging element.

34. The imaging device according to claim 32, wherein the detecting means has sensitivity to light rays in an infrared range.

35. A multi-wavelength imaging device, comprising:

a reflective optical device that converges light fluxes with only reflection surfaces; and

a detecting means that has sensitivity to light rays in a plurality of different wavelength ranges.

36. The multi-wavelength imaging device according to claim 35, wherein the plurality of different wavelength ranges are not less than two wavelength ranges selected from an infrared range, a visible range, and an ultraviolet range.

37. The multi-wavelength imaging device according to claim 35, wherein the reflective optical device is the reflective optical device according to any one of claims 1, 11, 12, and 15.

38. The multi-wavelength imaging device according to claim 35, wherein the detecting means includes a light flux separating means according to wavelengths, and a plurality of detecting surfaces that are responsive to the plurality of wavelength ranges, respectively.

39. The multi-wavelength imaging device according to claim 35, wherein the detecting means includes, in a same detecting surface, a plurality of regions that have sensitivity to light rays in different wavelength ranges, respectively.

40. The multi-wavelength imaging device according to claim 39, wherein the reflective optical device is the reflective optical device according to any one of claims 1, 11, 12, and 15.

41. A vehicle-mounted monitor, comprising:
an imaging device according to claim 32; and
a display means that conveys an obtained image to a driver.

42. A vehicle-mounted monitor, comprising:
a multi-wavelength imaging device according to claim 35 or 39; and
a display means that conveys an obtained image to a driver.

43. A reflective optical device, comprising a plurality of optical members, each in a shell-like shape, that are opposed to each other and bonded integrally so that a hollow space is formed therein and that have at least one reflection surface on surfaces on hollow space sides.

44. The reflective optical device according to claim 43, wherein at least one of the reflection surface is a free-form surface that does not have a rotational axis.

45. The reflective optical device according to claim 43, wherein the plurality of optical members are two optical members that are a front optical member and a rear optical member, and the hollow space is formed by providing the front optical member and the rear optical member integrally so that an opened side of the shell-like shape of the front optical member and an opened side of the shell-like shape of the rear optical member face and are bonded to each other.

46. The reflective optical device according to claim 43, wherein:
the optical members are resin moldings; and
a metallic thin film is formed on the reflection surface.

47. The reflective optical device according to claim 46, wherein a material of the metallic thin film is at least one selected from the group consisting of aluminum, gold, silver, copper and zinc.

48. The reflective optical device according to claim 46, wherein a SiO_2 thin film also is formed over the reflection surface.

49. The reflective optical device according to claim 43, wherein the optical members are made of a metallic material.

50. The reflective optical device according to claim 49, wherein the optical members are made of at least one metallic material selected from the group consisting of aluminum, gold, silver, copper, and zinc.

51. The reflective optical device according to claim 49, wherein a metallic thin film is formed on the reflection surface of the optical members made of the metallic material.

52. The reflective optical device according to claim 51, wherein a material of the metallic thin film is at least one selected from the group consisting of aluminum, gold, silver, copper, and zinc.

53. The reflective optical device according to claim 49, wherein a SiO_2 film also is formed over the reflection surface.

54. The reflective optical device according to claim 43, wherein at least one of the plurality of optical members includes an aperture for image formation.

55. The reflective optical device according to claim 54, wherein a window member that transmits light fluxes in a wavelength range necessary for image formation is provided at the aperture for image formation.

56. The reflective optical device according to claim 54, wherein a window member that transmits light fluxes in a wavelength range necessary for image formation and that blocks light fluxes in the other wavelength ranges is provided at the aperture for image formation.

57. The reflective optical device according to claim 54, wherein a window member made of a material selected from the group consisting of germanium, silicon, polyethylene, CaF_2, BaF_2, and ZnSe is provided at the aperture for image formation.

58. The reflective optical device according to claim 55, wherein the window member is in a flat plate form.

59. The reflective optical device according to claim 55, wherein the window member has a lens function.

60. The reflective optical device according to claim 54, wherein a window member that has an optical property of preventing at least infrared rays in a specific wavelength range among incident infrared rays from passing therethrough is provided at the aperture for image formation.

61. The reflective optical device according to claim 60, wherein the window member has an optical property of reflecting infrared rays, and is composed of a transparent base on which a dielectric multi-layer film is provided.

62. The reflective optical device according to claim 61, wherein the transparent base is made of a glass material.

63. The reflective optical device according to claim 61, wherein the transparent base is made of a resin material.

64. The reflective optical device according to claim 61, wherein the transparent base is made of at least one selected from the group consisting of CaF_2, BaF_2, and ZnSe.

65. The reflective optical device according to claim 60, wherein the window member is made of a glass material having an optical property of absorbing infrared rays.

66. The reflective optical device according to claim 60, wherein the window member is made of a resin material having an optical property of absorbing infrared rays.

67. The reflective optical device according to claim 60, wherein the window member prevents infrared rays in a near infrared range from passing therethrough.

68. The reflective optical device according to claim 67, wherein the near infrared range is a range of 700nm to 1100nm.

69. The reflective optical device according to claim 60, wherein the window member is in a flat plate form.

70. The reflective optical device according to claim 60, wherein the window member has a lens function.

71. The reflective optical device according to claim 54, wherein a film having an optical property of not reflecting at least infrared rays in a specific wavelength range among incident infrared rays is formed on each reflection surface.

72. The reflective optical device according to claim 71, wherein the film has an optical property of not reflecting infrared rays in a range of wavelengths longer than those in a visible range.

73. The reflective optical device according to claim 72, wherein the range of wavelengths longer than those in the visible range is a range of wavelengths longer than 700nm.

74. The reflective optical device according to claim 71, wherein the film has an optical property of not reflecting infrared rays in a near infrared range.

75. The reflective optical device according to claim 74, wherein the near infrared range is a range of 700nm to 1100nm.

76. The reflective optical device according to claim 43, wherein at least one of the plurality of optical members includes an aperture for allowing an image to be formed on a member with photosensitivity.

77. A reflective solid-state optical device, comprising a solid device body formed with an optical medium having an optical property of preventing at least infrared rays in a specific wavelength range among incident infrared

rays from passing therethrough, wherein at least one reflection surface is formed on the device body, the reflection surface being composed of a surface of the device body and a film formed on the surface of the device body.

78. The reflective solid-state optical device according to claim 77, wherein the surface of the device body constituting the at least one reflection surface is formed to be a free-form surface that does not have a rotational axis.

79. The reflective solid-state optical device according to claim 77, wherein the optical medium is made of a material having an optical property of preventing infrared rays in a range of wavelengths longer than those in a visible range.

80. The reflective solid-state optical device according to claim 79, wherein the range of wavelengths longer than those in the visible range is a range of wavelengths longer than 700nm.

81. The reflective solid-state optical device according to claim 77, wherein the optical medium is made of a material having an optical property of preventing infrared rays in a near infrared range from passing therethrough.

82. The reflective solid-state optical device according to claim 81, wherein the near infrared range is a range of 700nm to 1100nm.

83. An imaging device, comprising the reflective optical device according to any one of claims 43 to 76, wherein an imaging element is provided at a portion of the reflective optical device where an image is formed.

84. The imaging device according to claim 83, wherein the imaging element has sensitivity to a visible range.

85. An imaging device, comprising the reflective optical device according to any one of claims 43 to 76, wherein an imaging element having sensitivity to a visible range is provided at a portion of the reflective optical device where an image is formed.

86. An imaging device, comprising the reflective optical device according to any one of claims 43 to 59, wherein an imaging element having sensitivity to a visible range and an infrared range is provided at a portion of the reflective optical device where an image is formed.

87. An imaging device, comprising the reflective optical device according to any one of claims 67, 68, 74, and 75, wherein an imaging element having sensitivity to a visible range and an infrared range is provided at a portion of the reflective optical device where an image is formed.

88. An imaging device, comprising the reflective solid-state optical device according to any one of claims 77 to 82, wherein an imaging element is provided at a portion of the reflective solid-state optical device where an image is formed.

89. The imaging device according to claim 88, wherein the imaging element has sensitivity to a visible range.

90. An imaging device, comprising the reflective solid-state optical device according to claim 81 or 82, wherein an imaging element having sensitivity to a visible range and an infrared range is provided at a portion of the reflective solid-state optical device where an image is formed.

91. A video camera device, comprising the imaging device according to claim 83.

92. A video camera device, comprising the imaging device according to claim 88.

93. A vehicle-mounted monitor, comprising the imaging device according to claim 83.

94. A vehicle-mounted monitor, comprising the imaging device according to claim 88.

ABSTRACT

Two reflection surfaces that are a first reflection surface (2) and a second reflection surface (3), each in a non-axisymmetric form, are disposed in the stated order in a direction in which light fluxes travel, and bring light fluxes from an object into focus on an image surface (4). The first reflection surface (2) and the second reflection surface (3) are provided eccentrically, and each of the first reflection surface (2) and the second refection surface (3) is concave in a cross-sectional shape taken along a plane containing a center of the image surface (4) and vertices of the reflection surfaces (2, 3). This ensures that light fluxes are guided to the image surface without being blocked, whereby an excellent image can be formed. Thus, a reflective optical device with a wider angle and improved performance can be provided.

09/913018

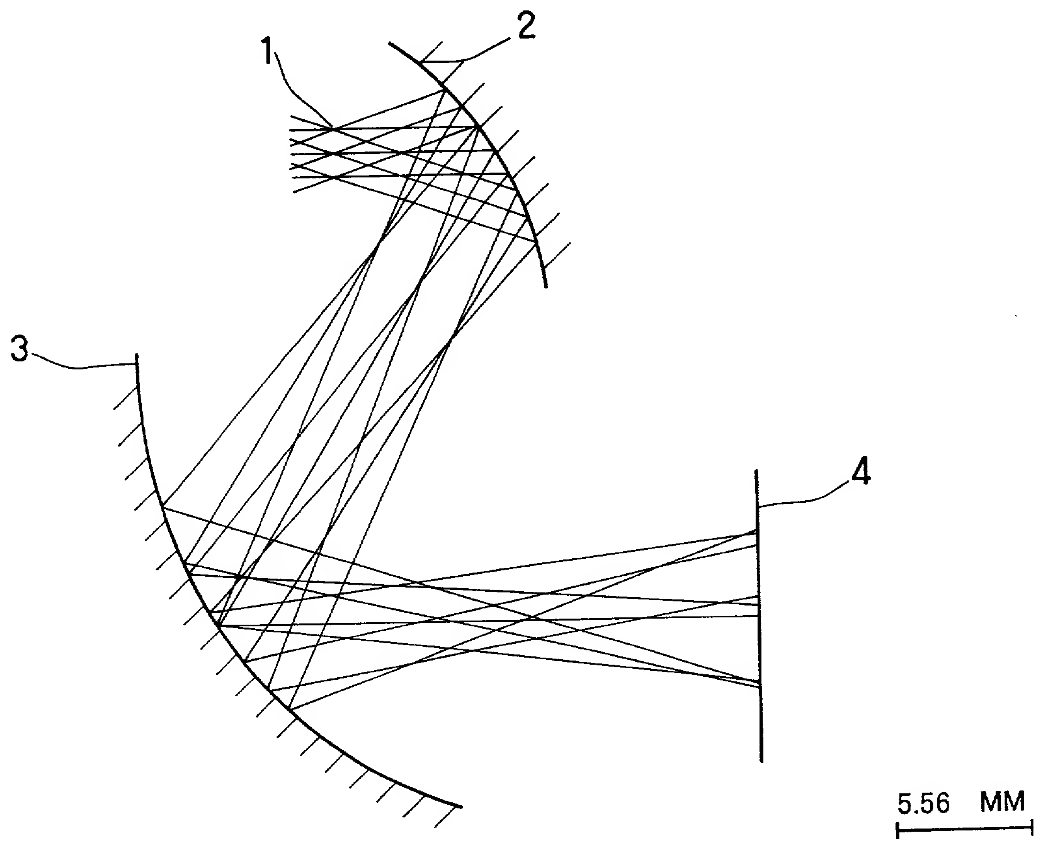


FIG. 1

09/913010

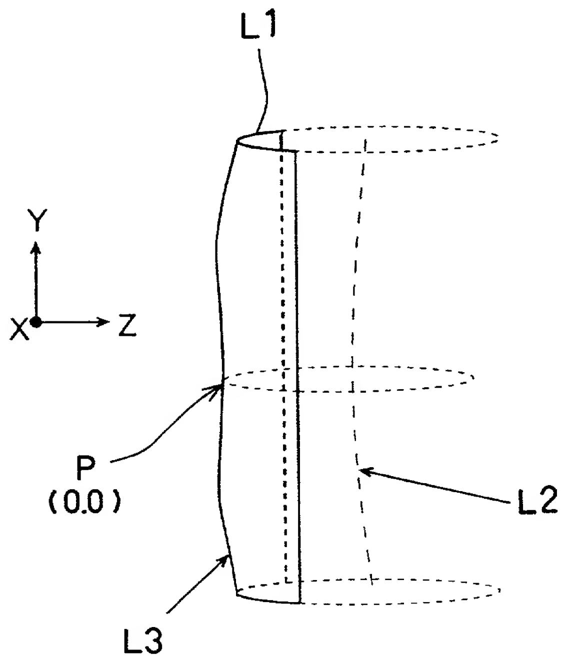


FIG . 2

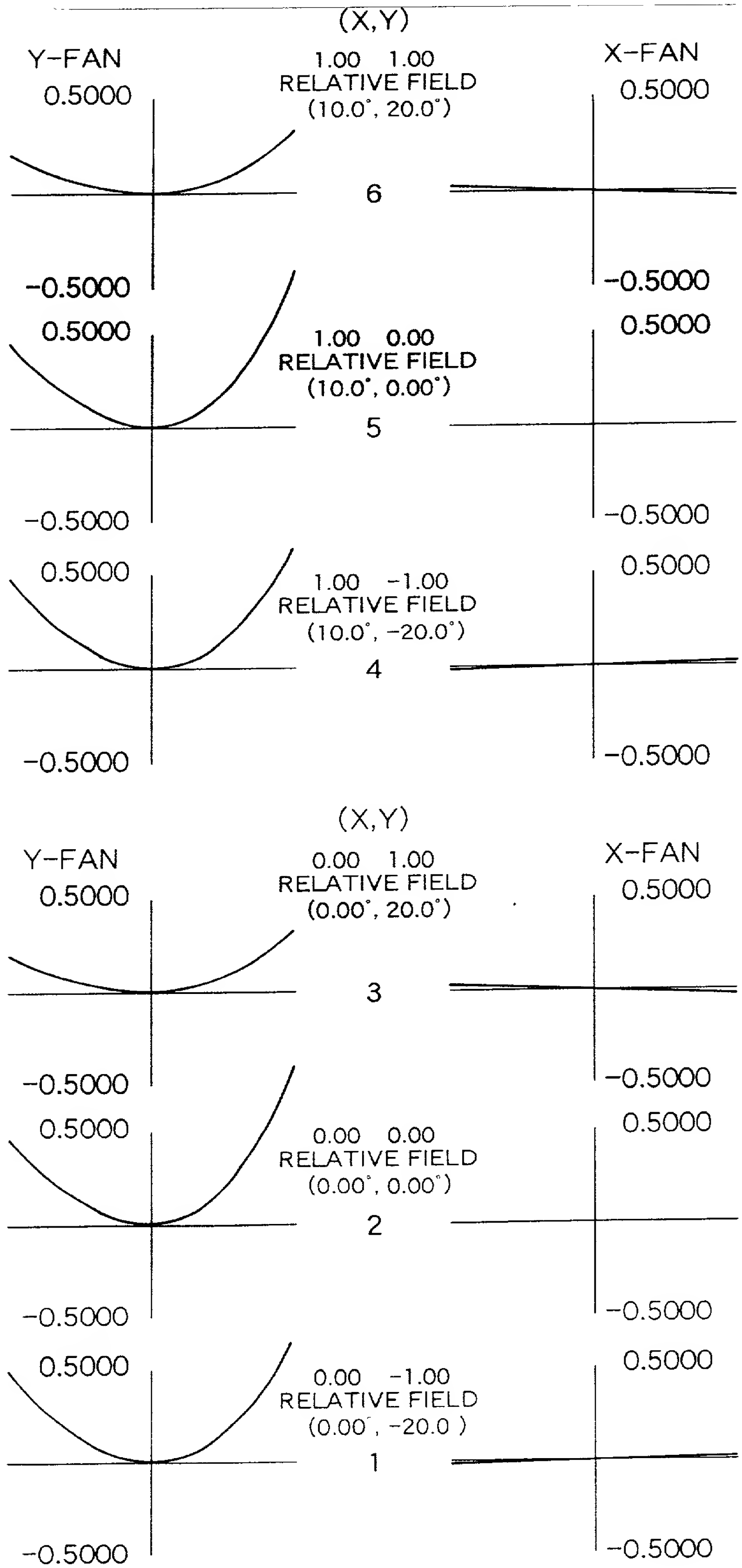

(X,Y)
Y-FAN
X-FAN
1.00 1.00
RELATIVE FIELD
(10.0°, 20.0°)
6
1.00 0.00
RELATIVE FIELD
(10.0°, 0.00°)
5
1.00 -1.00
RELATIVE FIELD
(10.0°, -20.0°)
4
(X,Y)
Y-FAN
X-FAN
0.00 1.00
RELATIVE FIELD
(0.00°, 20.0°)
3
0.00 0.00
RELATIVE FIELD
(0.00°, 0.00°)
2
0.00 -1.00
RELATIVE FIELD
(0.00°, -20.0)
1
0.5000
-0.5000

FIG. 3

09/913018

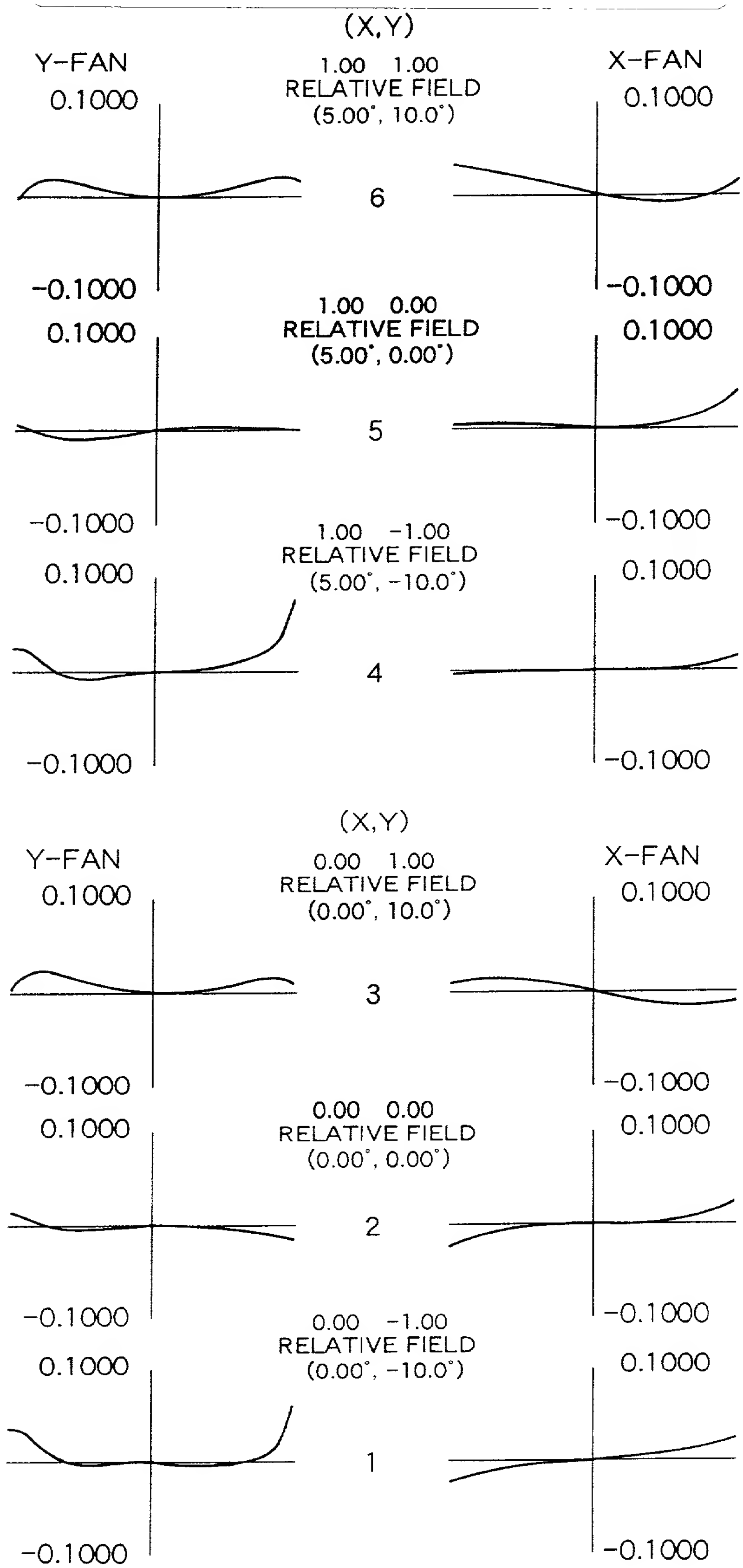


FIG. 4

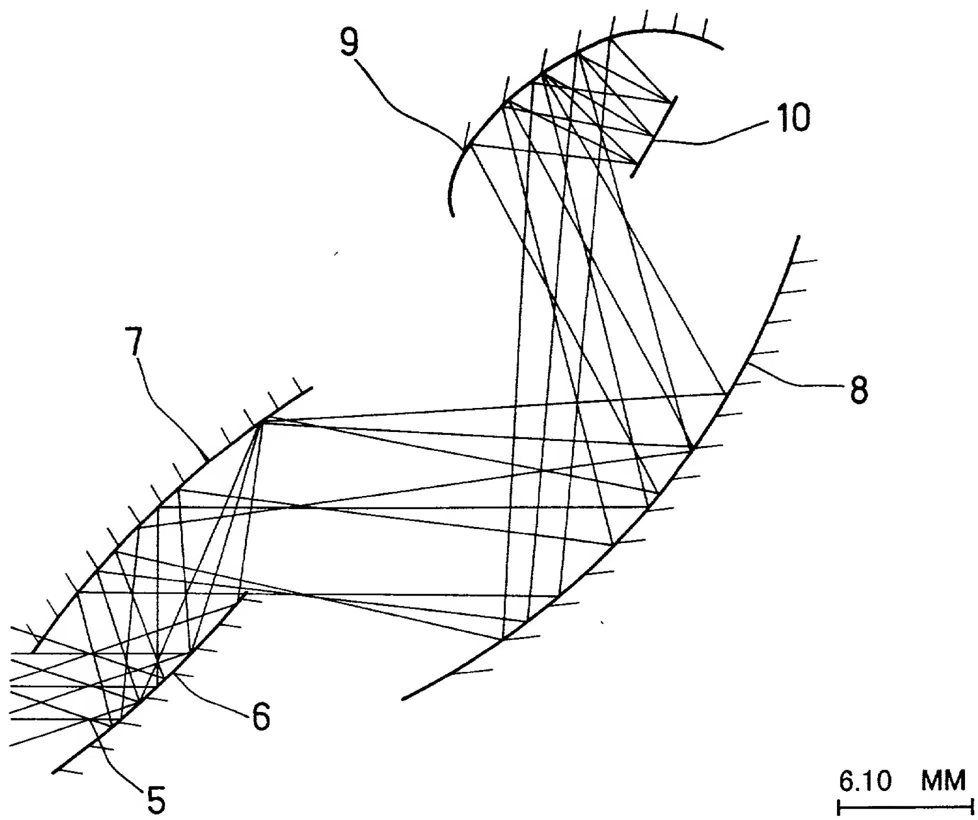
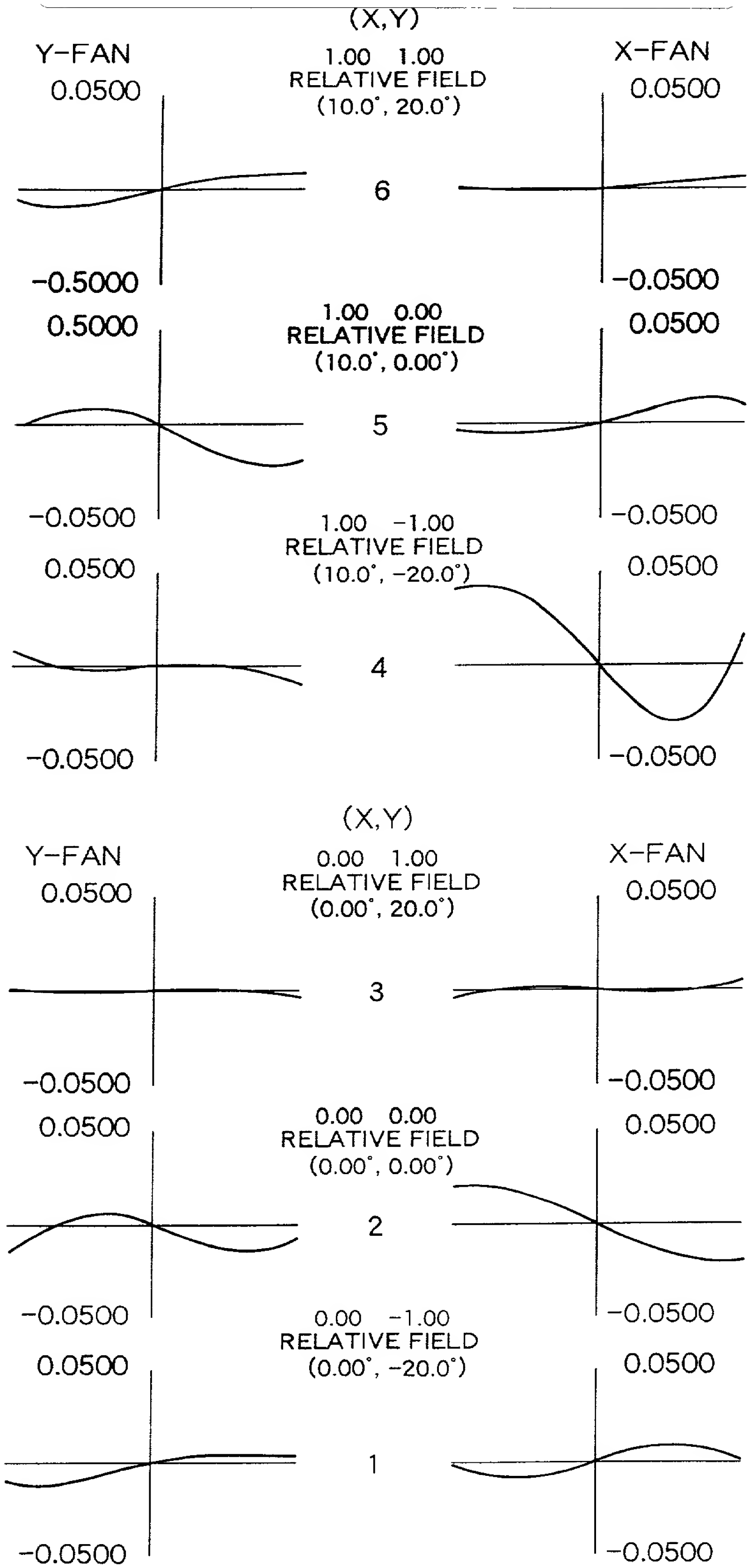


FIG . 5


(X,Y)
Y-FAN
X-FAN
1.00 1.00
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(10.0°, 20.0°)
0.0500
0.0500
6
-0.5000
-0.0500
1.00 0.00
RELATIVE FIELD
(10.0°, 0.00°)
0.5000
0.0500
5
-0.0500
-0.0500
1.00 -1.00
RELATIVE FIELD
(10.0°, -20.0°)
0.0500
0.0500
4
-0.0500
-0.0500
(X,Y)
Y-FAN
X-FAN
0.00 1.00
RELATIVE FIELD
(0.00°, 20.0°)
0.0500
0.0500
3
-0.0500
-0.0500
0.00 0.00
RELATIVE FIELD
(0.00°, 0.00°)
0.0500
0.0500
2
-0.0500
-0.0500
0.00 -1.00
RELATIVE FIELD
(0.00°, -20.0°)
0.0500
0.0500
1
-0.0500
-0.0500

FIG. 6

09/913018

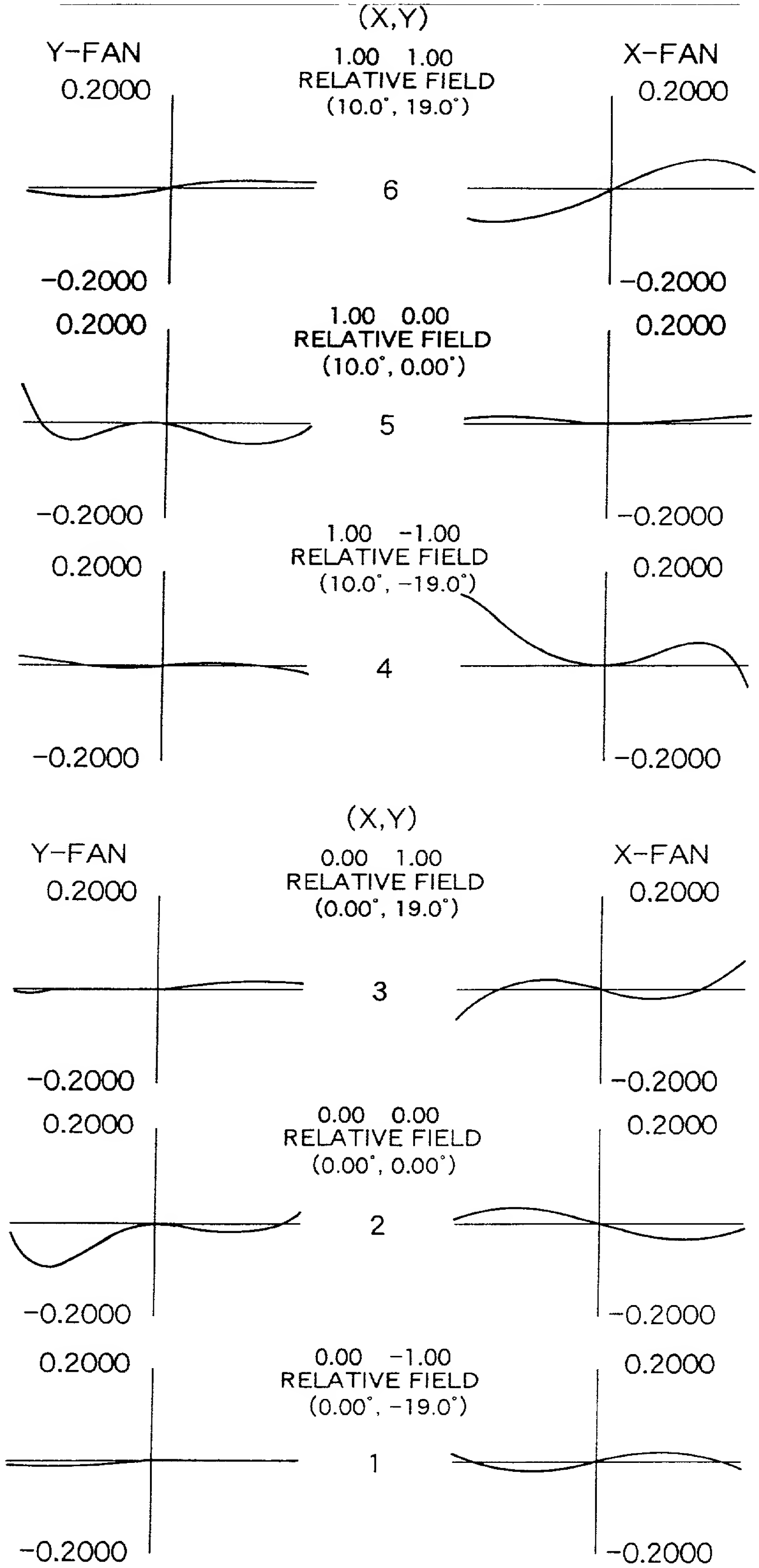

FIG. 7

09/913018

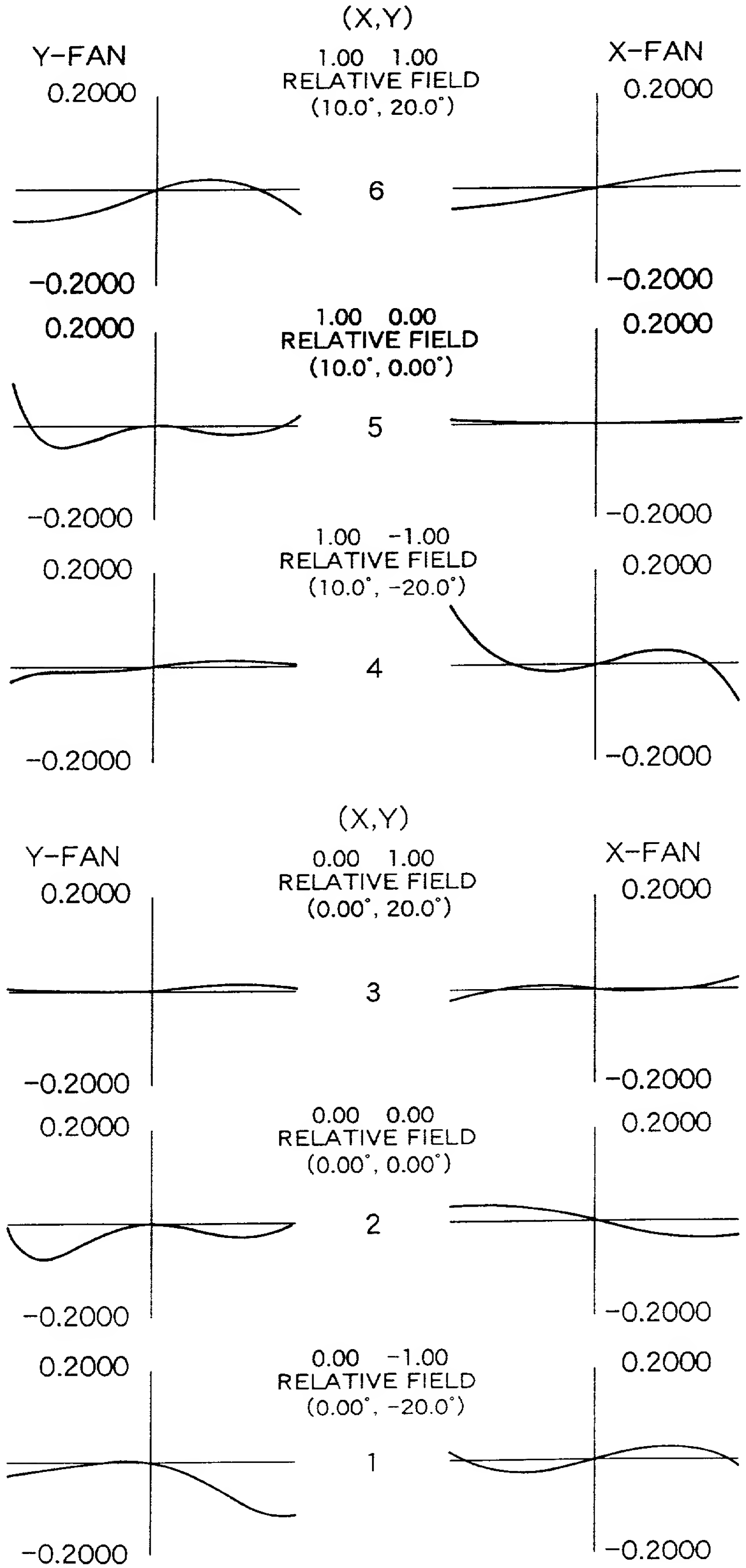

FIG. 8

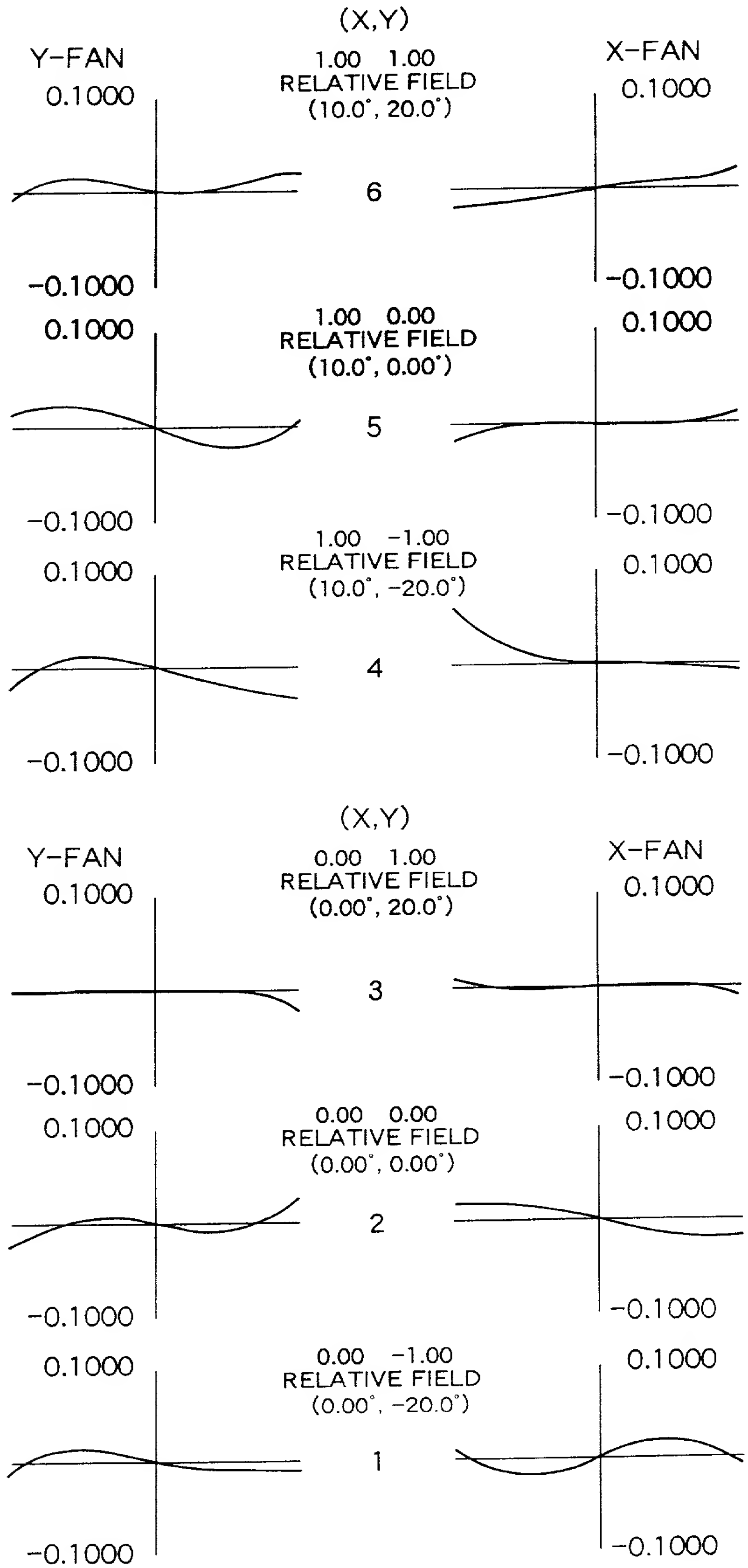
(X,Y)
Y-FAN
X-FAN
1.00 1.00
RELATIVE FIELD
(10.0°, 20.0°)
6
1.00 0.00
RELATIVE FIELD
(10.0°, 0.00°)
5
1.00 -1.00
RELATIVE FIELD
(10.0°, -20.0°)
4
(X,Y)
Y-FAN
X-FAN
0.00 1.00
RELATIVE FIELD
(0.00°, 20.0°)
3
0.00 0.00
RELATIVE FIELD
(0.00°, 0.00°)
2
0.00 -1.00
RELATIVE FIELD
(0.00°, -20.0°)
1
0.1000
-0.1000

FIG. 9

09/913018

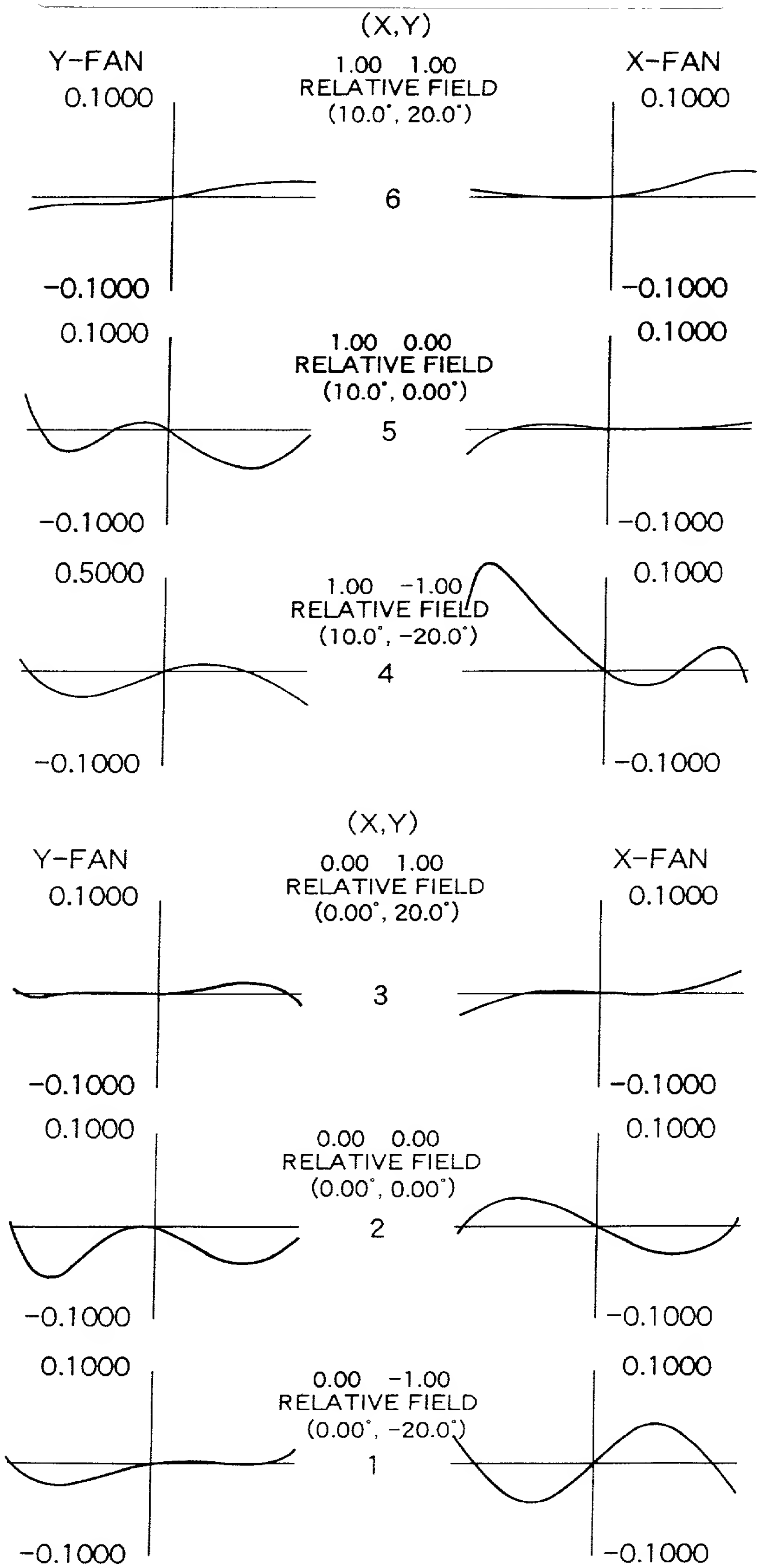

FIG. 10

09/913018

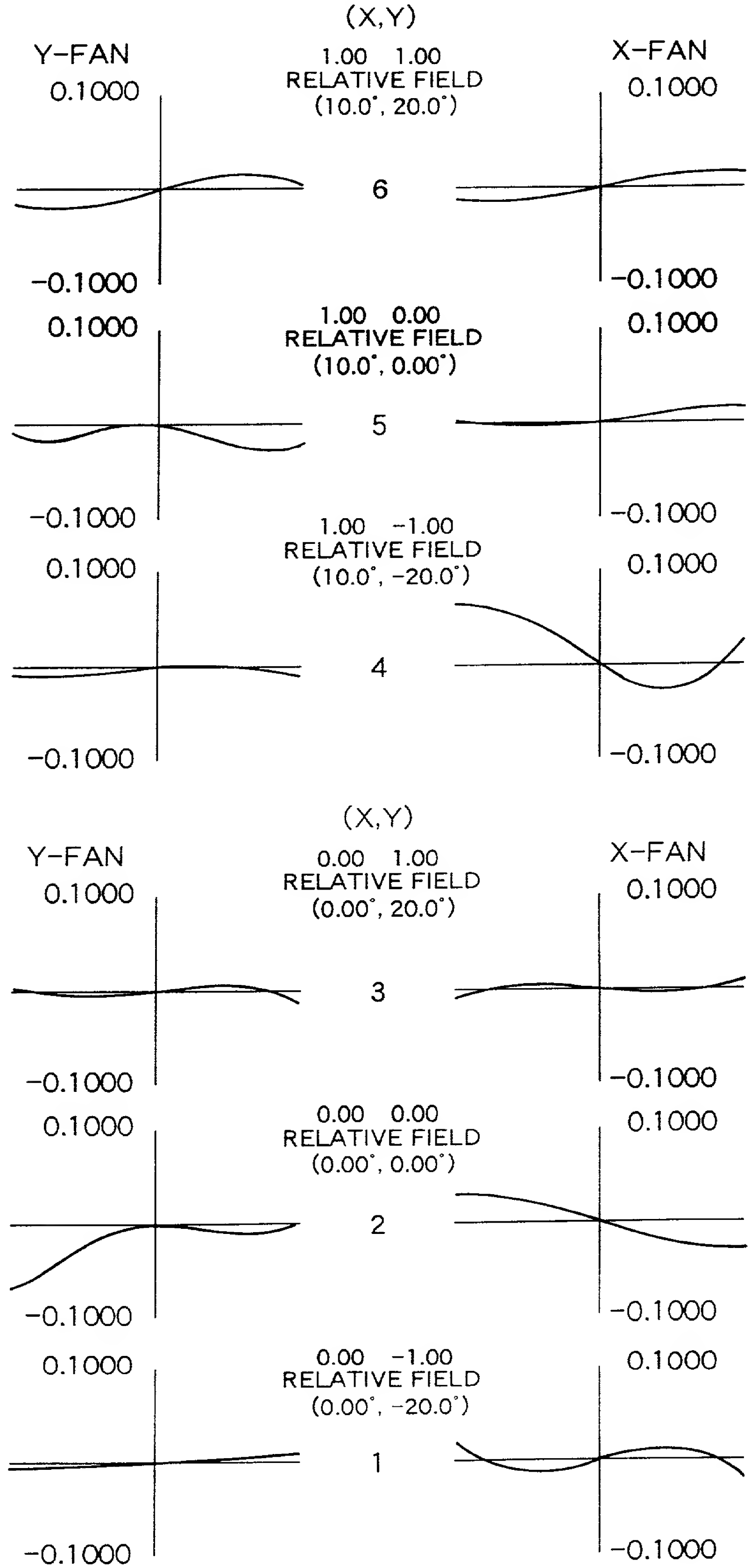

FIG. 11

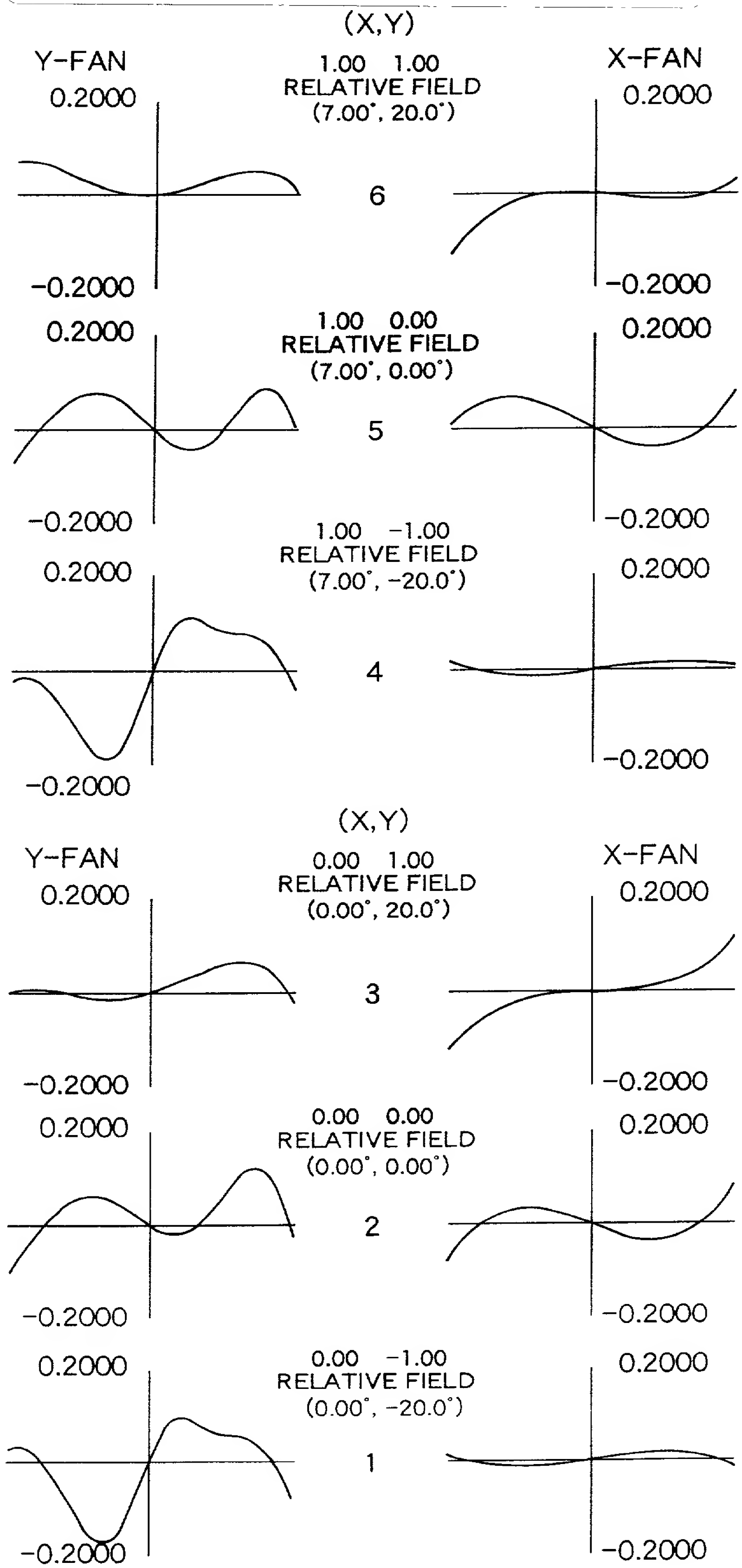
(X,Y)
Y-FAN
X-FAN
1.00 1.00
RELATIVE FIELD
(7.00°, 20.0°)
6
1.00 0.00
RELATIVE FIELD
(7.00°, 0.00°)
5
1.00 -1.00
RELATIVE FIELD
(7.00°, -20.0°)
4
(X,Y)
Y-FAN
X-FAN
0.00 1.00
RELATIVE FIELD
(0.00°, 20.0°)
3
0.00 0.00
RELATIVE FIELD
(0.00°, 0.00°)
2
0.00 -1.00
RELATIVE FIELD
(0.00°, -20.0°)
1
0.2000
-0.2000

FIG. 12

09/913018

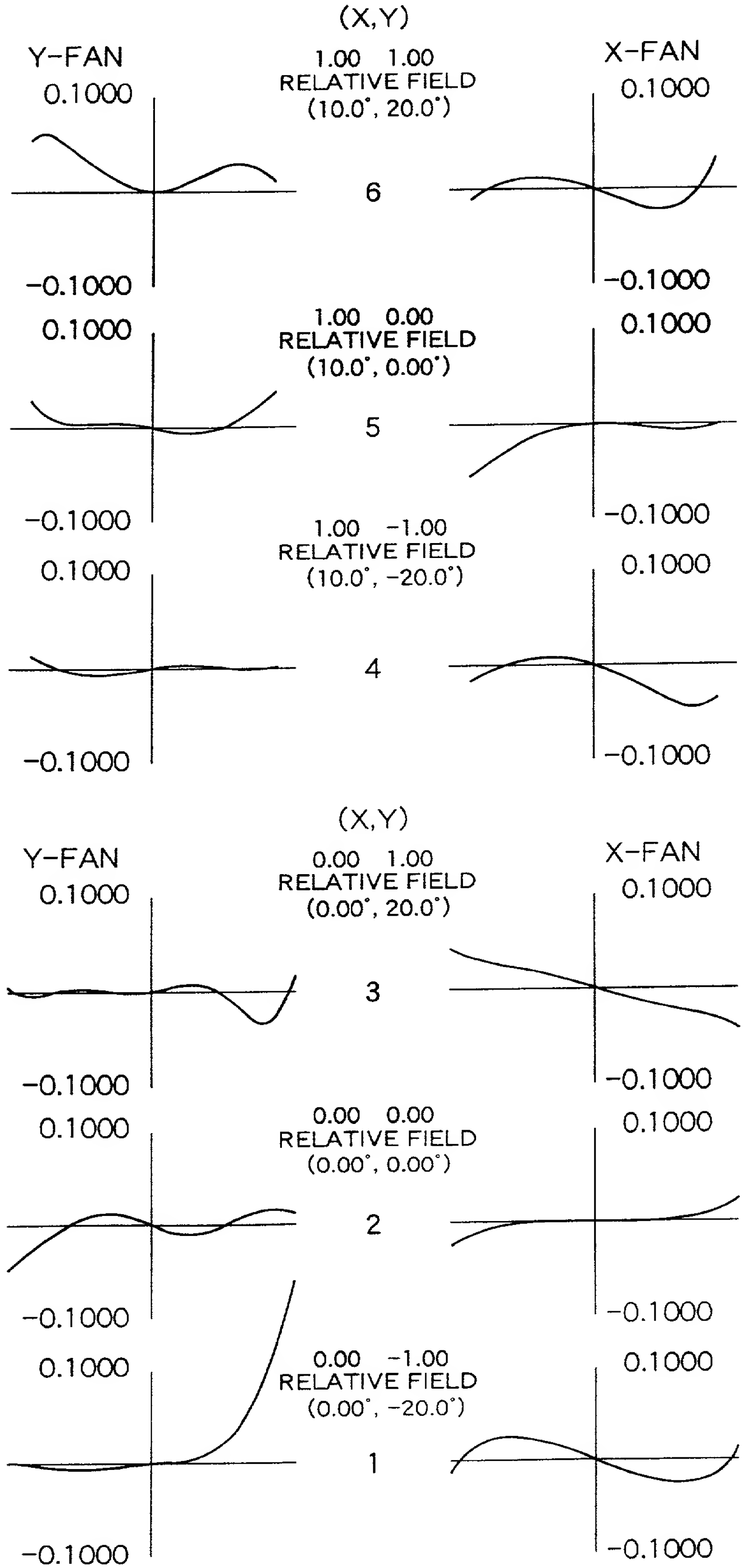

FIG. 13

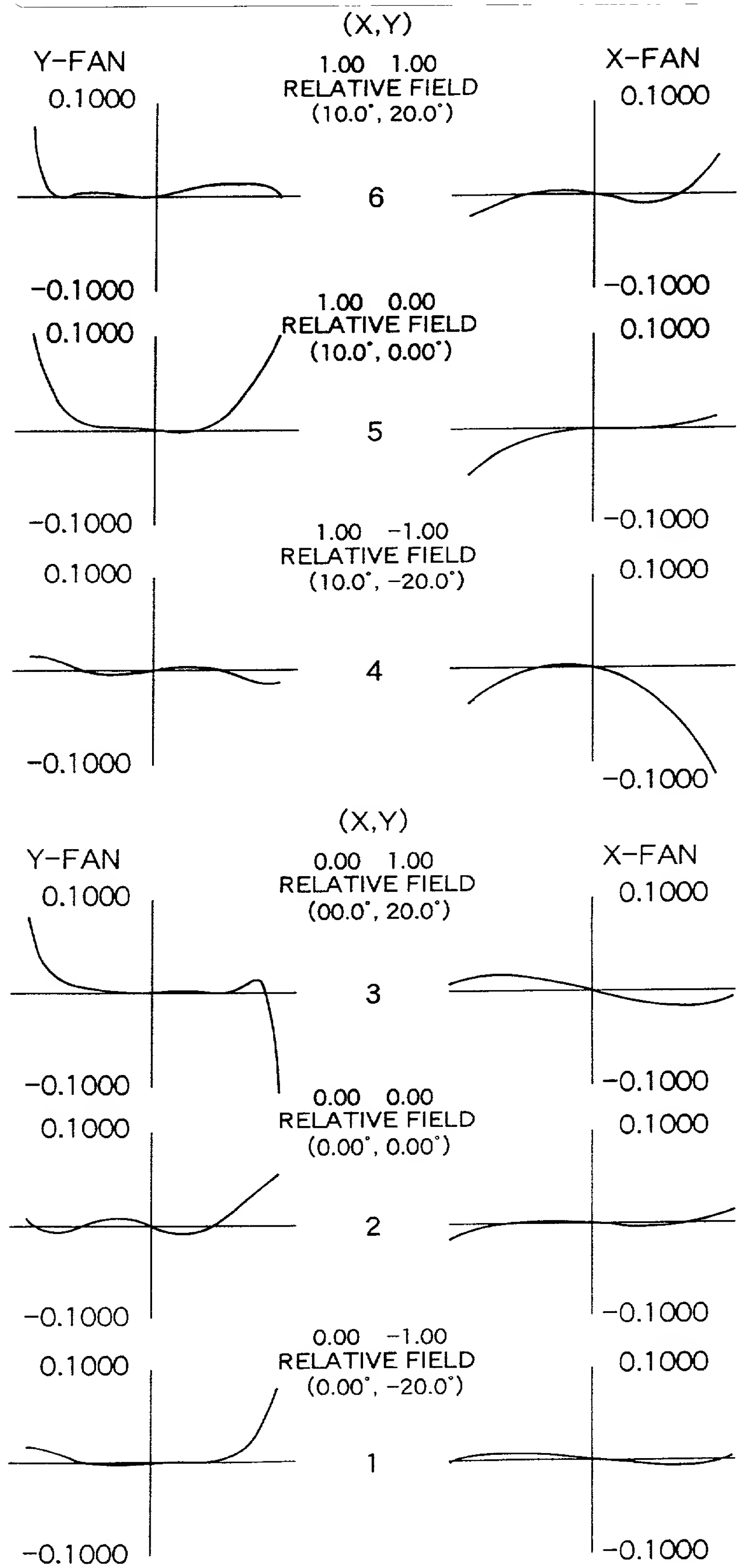
(X,Y)
Y-FAN
X-FAN
1.00 1.00
RELATIVE FIELD
(10.0°, 20.0°)
6
1.00 0.00
RELATIVE FIELD
(10.0°, 0.00°)
5
1.00 -1.00
RELATIVE FIELD
(10.0°, -20.0°)
4
(X,Y)
Y-FAN
X-FAN
0.00 1.00
RELATIVE FIELD
(00.0°, 20.0°)
3
0.00 0.00
RELATIVE FIELD
(0.00°, 0.00°)
2
0.00 -1.00
RELATIVE FIELD
(0.00°, -20.0°)
1
0.1000
-0.1000

FIG. 14

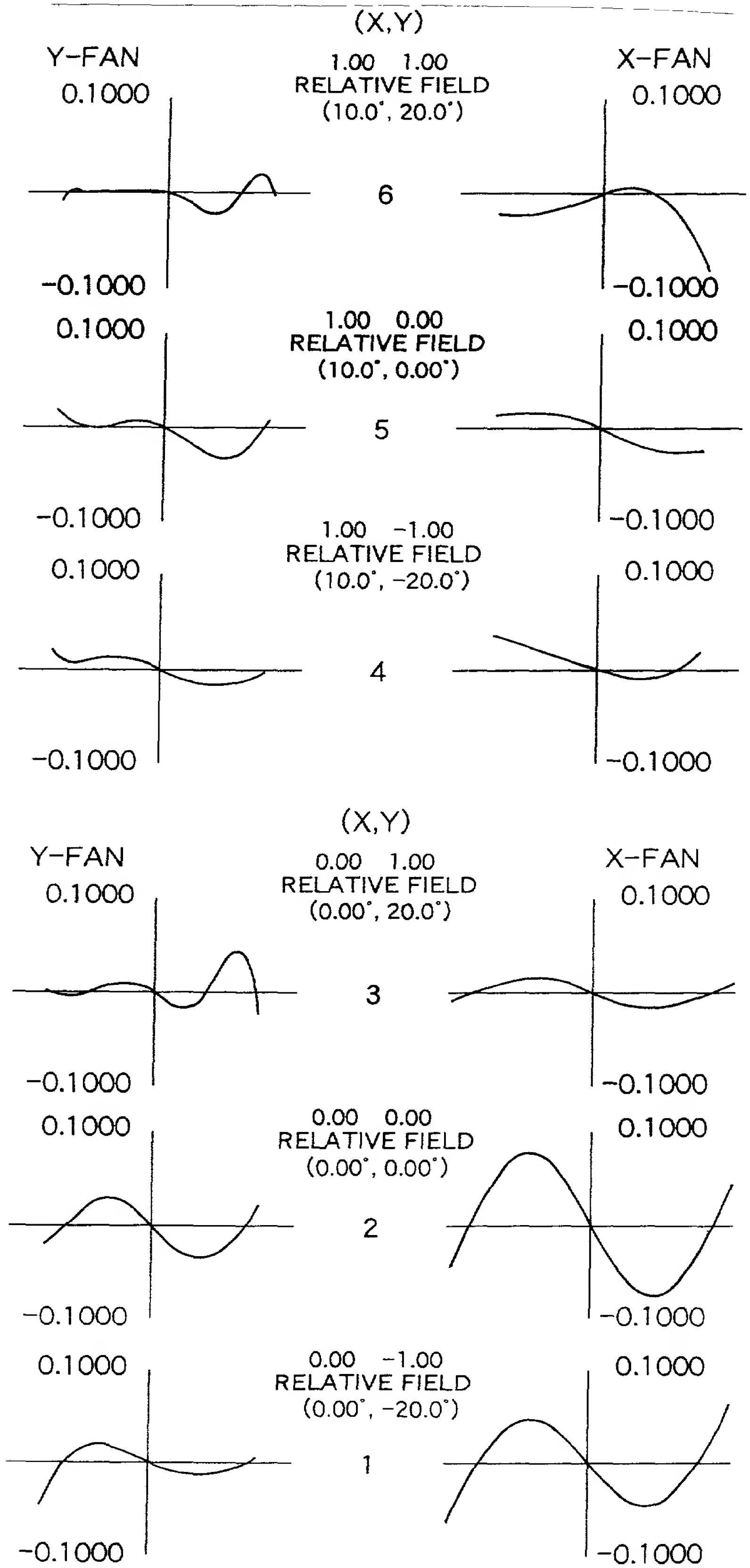
(X,Y)
Y-FAN
X-FAN
1.00 1.00
RELATIVE FIELD
(10.0°, 20.0°)
6
1.00 0.00
RELATIVE FIELD
(10.0°, 0.00°)
5
1.00 −1.00
RELATIVE FIELD
(10.0°, −20.0°)
4
(X,Y)
Y-FAN
X-FAN
0.00 1.00
RELATIVE FIELD
(0.00°, 20.0°)
3
0.00 0.00
RELATIVE FIELD
(0.00°, 0.00°)
2
0.00 −1.00
RELATIVE FIELD
(0.00°, −20.0°)
1
0.1000
−0.1000

FIG. 15

09/913018

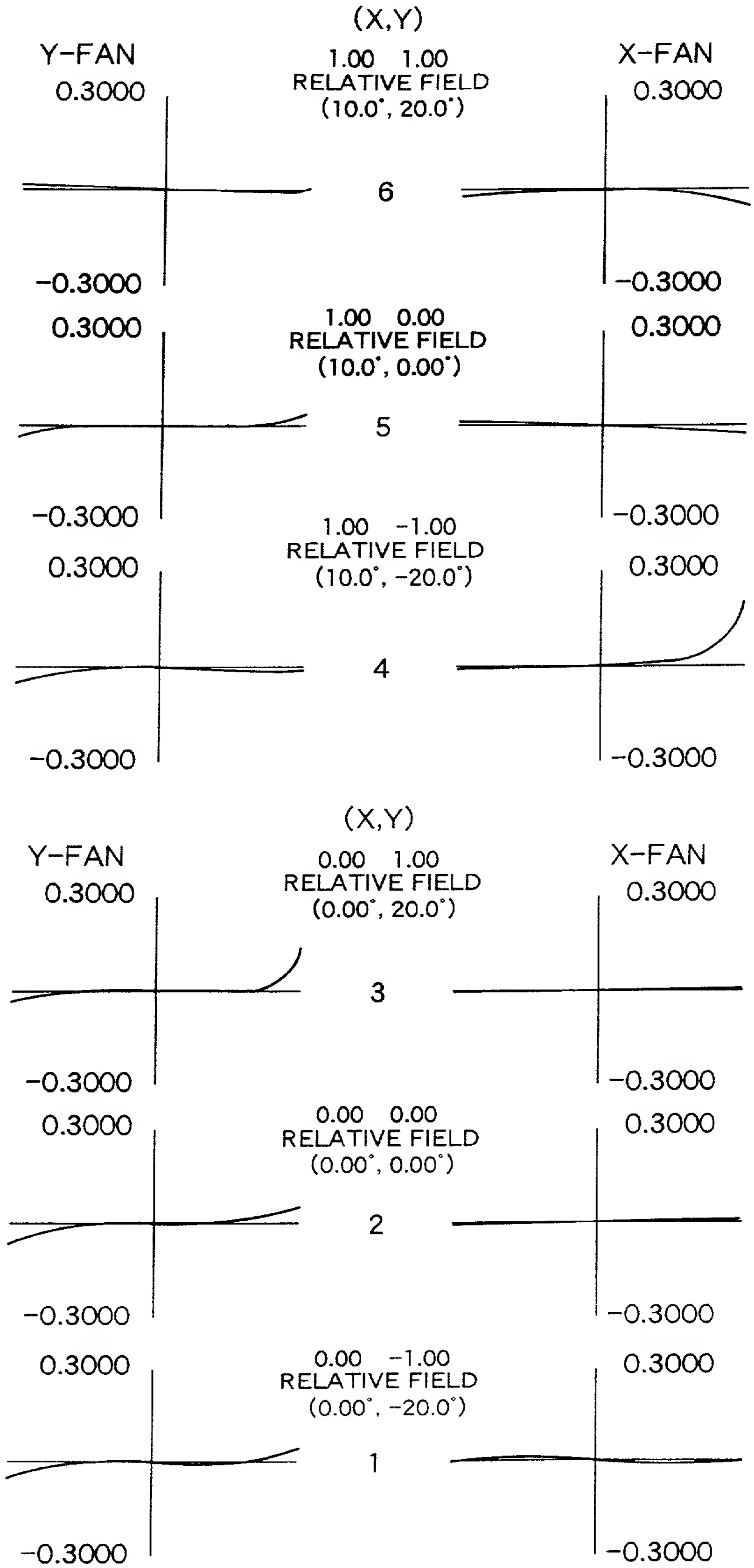

FIG. 16

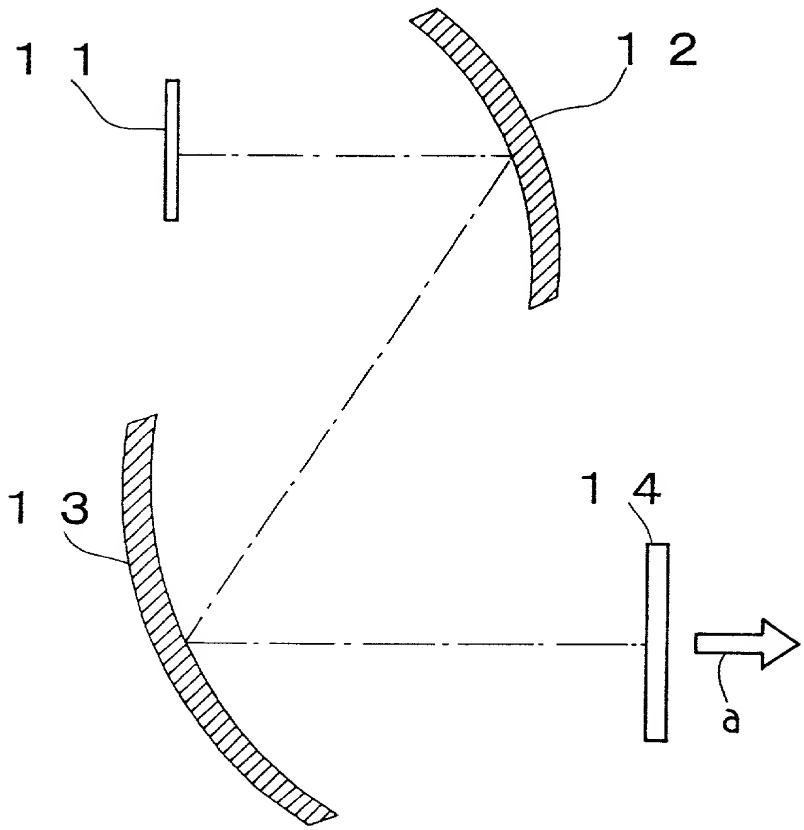

FIG. 17

09/913018

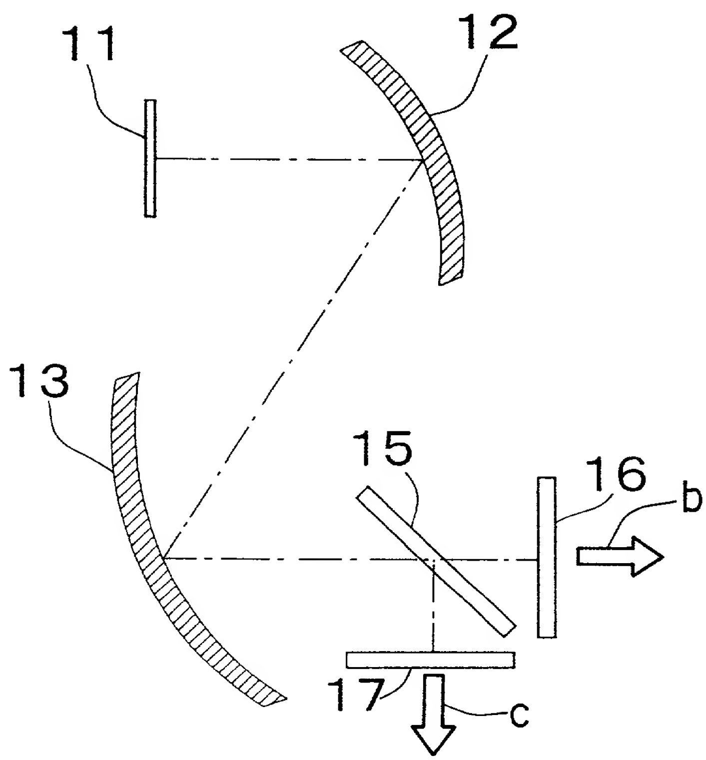

FIG . 18

09/913018

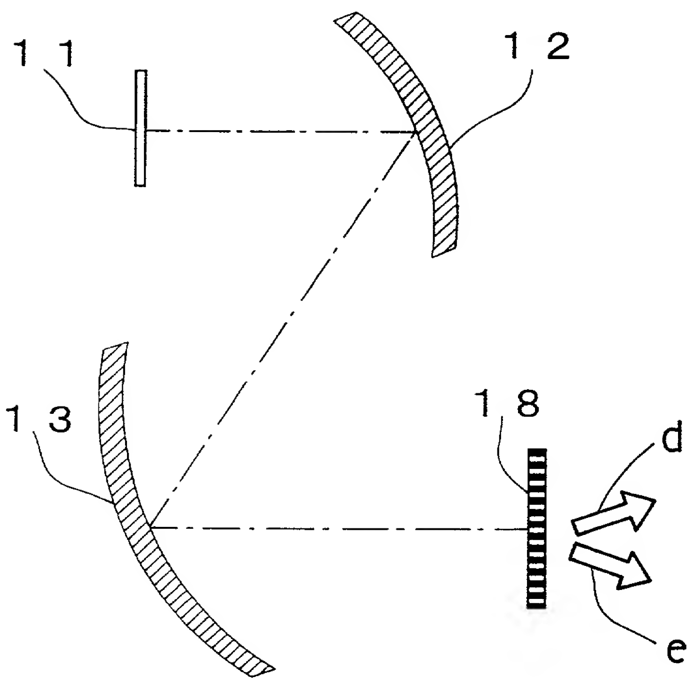

FIG. 19

09/513018

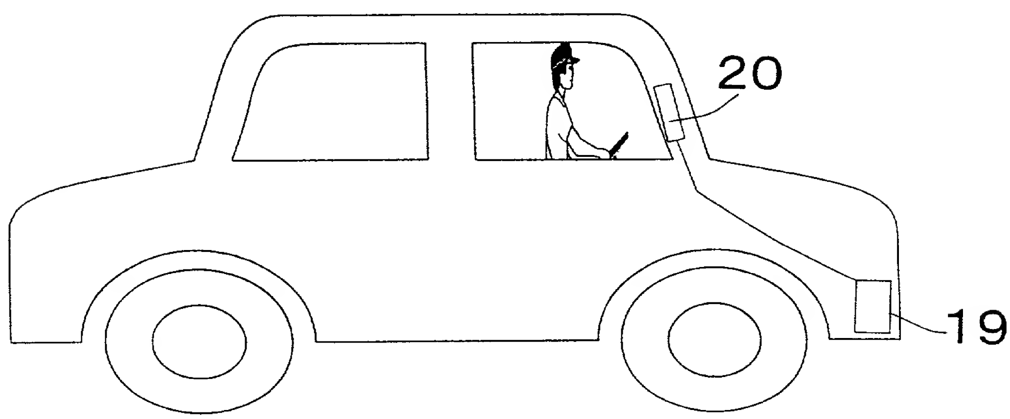

FIG. 20

Inventor: Yoshikawa et al.
Docket No.: 10873.779USWO
Title: REFLECTIVE OPTICAL DEVICE, AND REFLECTIVE SOLID-STATE OPTICAL DEVICE. . .
Attorney Name: Douglas P. Mueller
Phone No.: 612.371.5237

09/913018

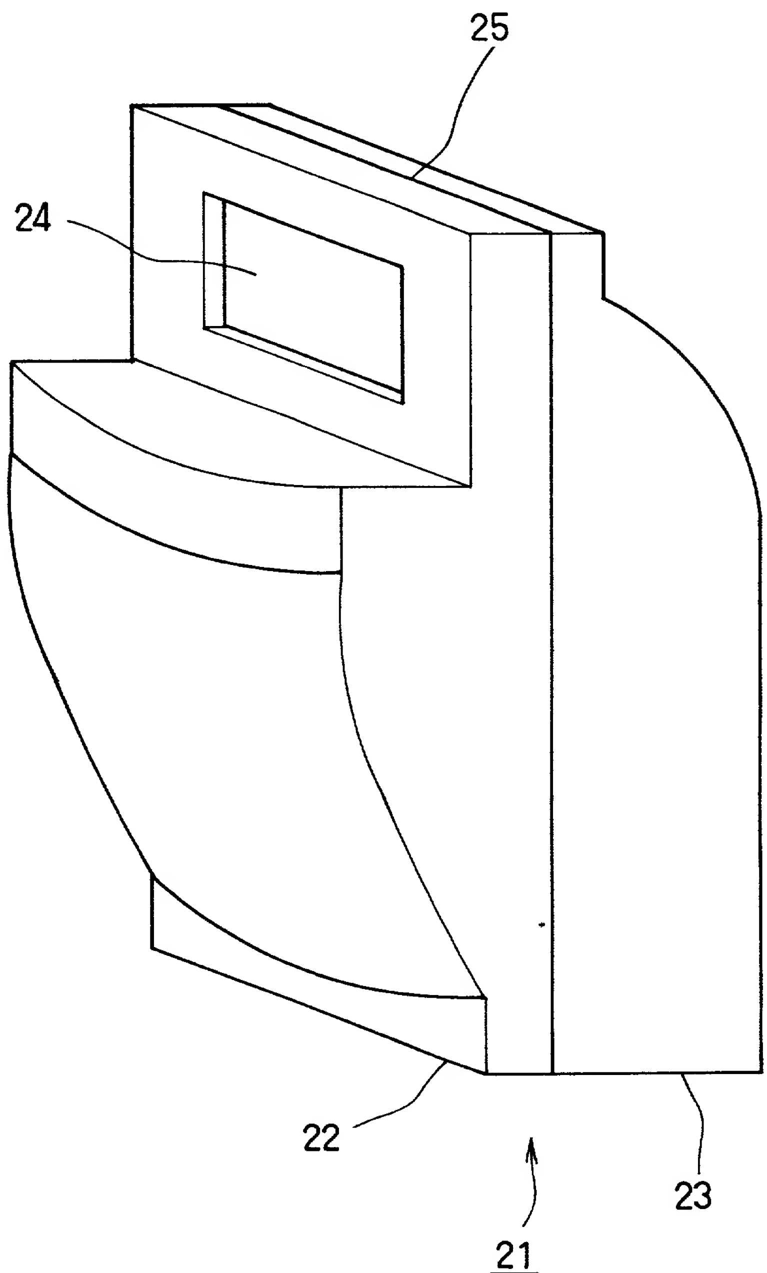

FIG. 21

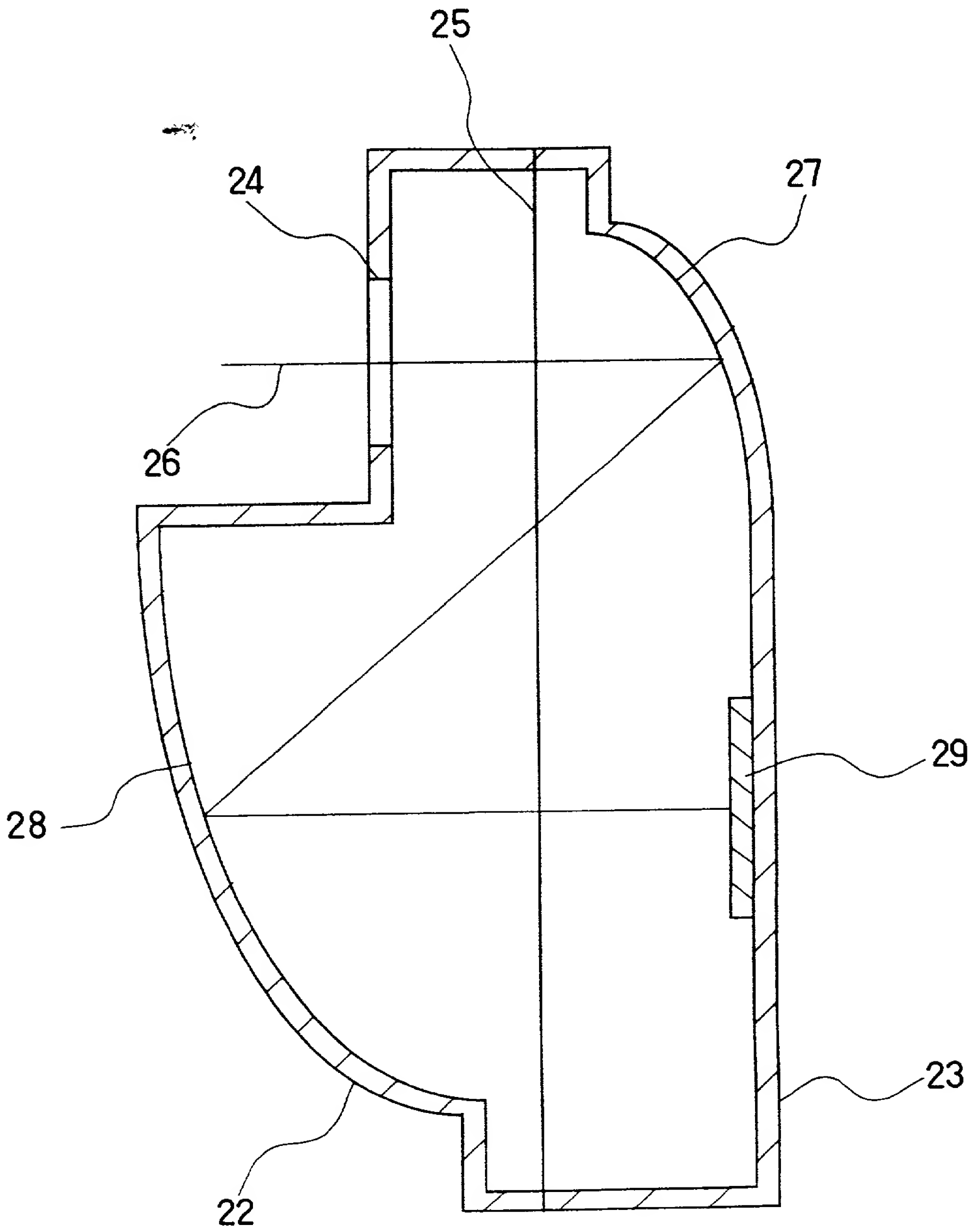

FIG. 22

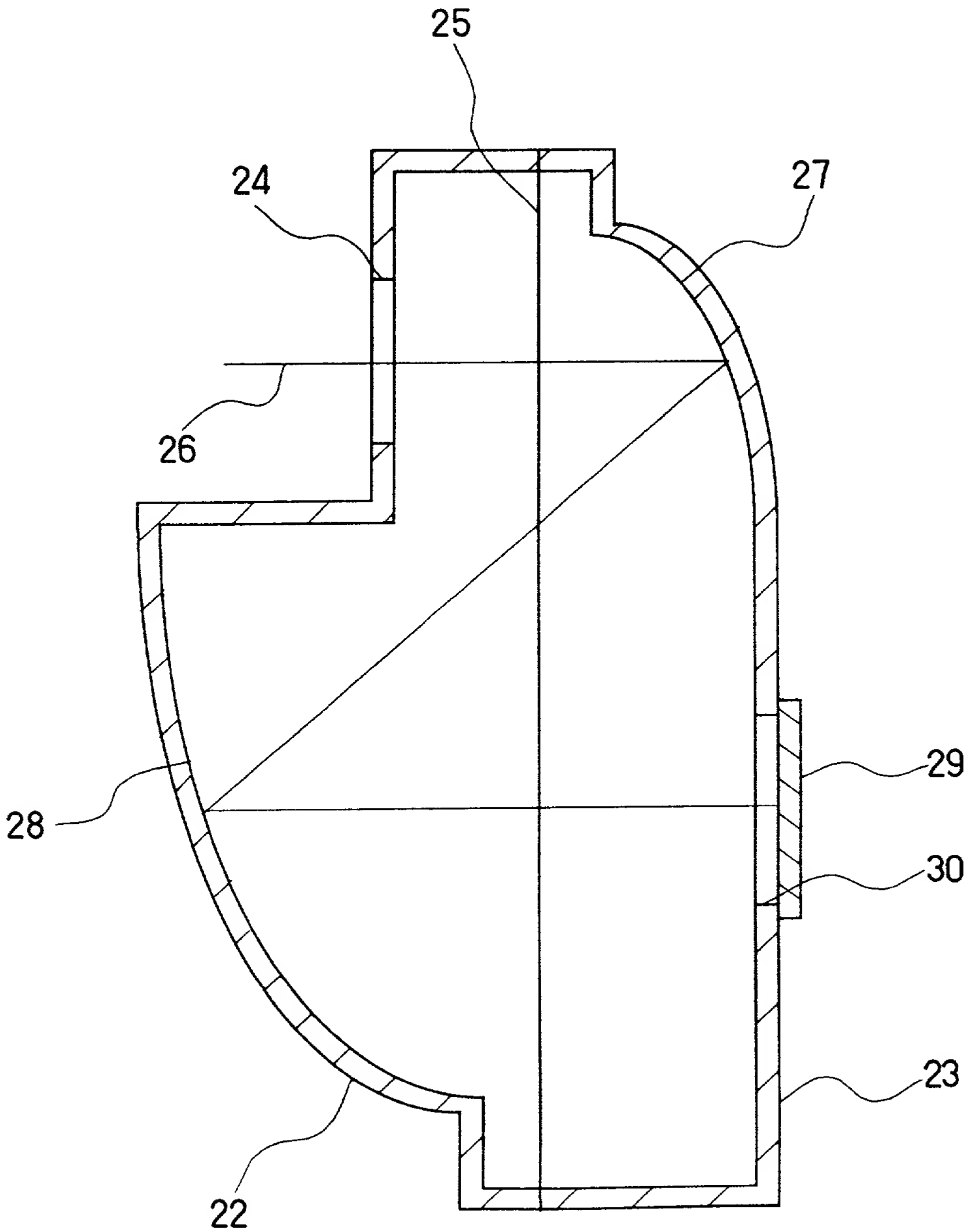

FIG. 23

09/913018

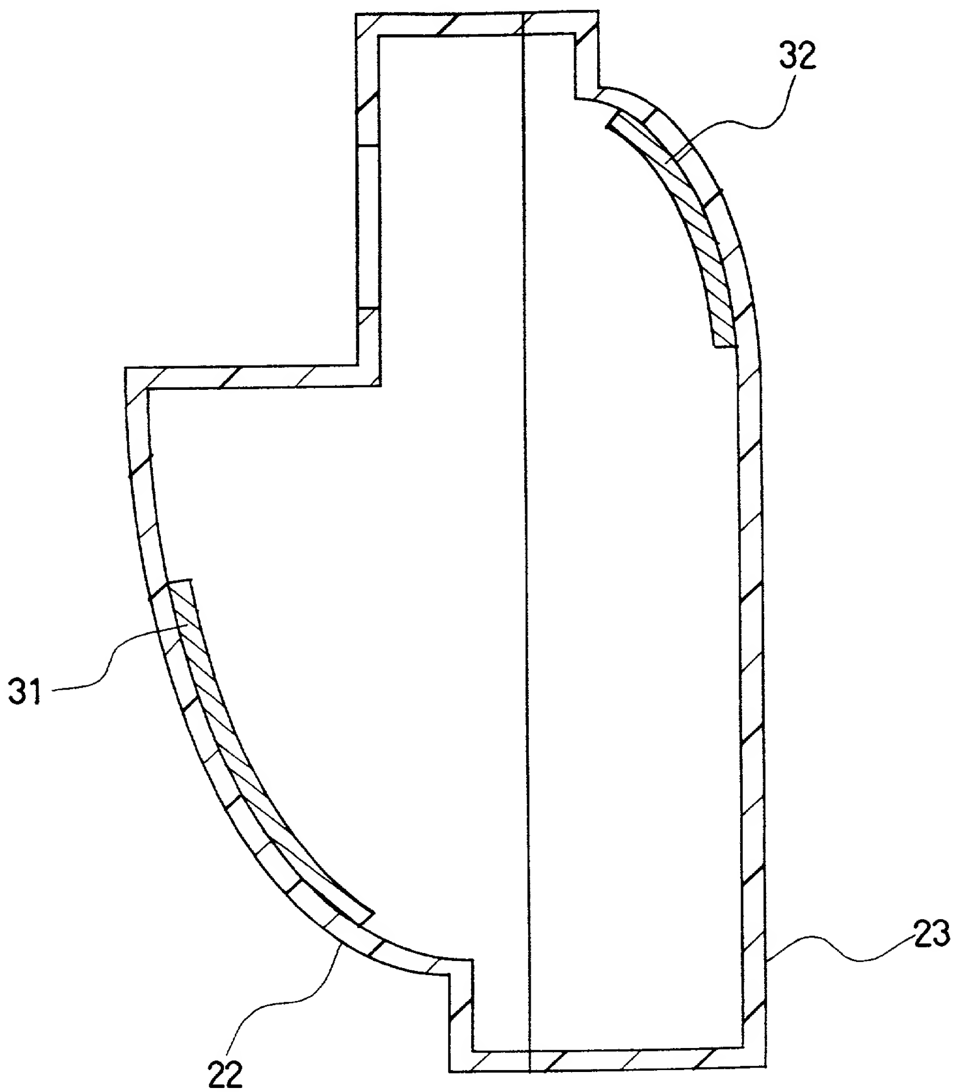

FIG. 24

09/913018

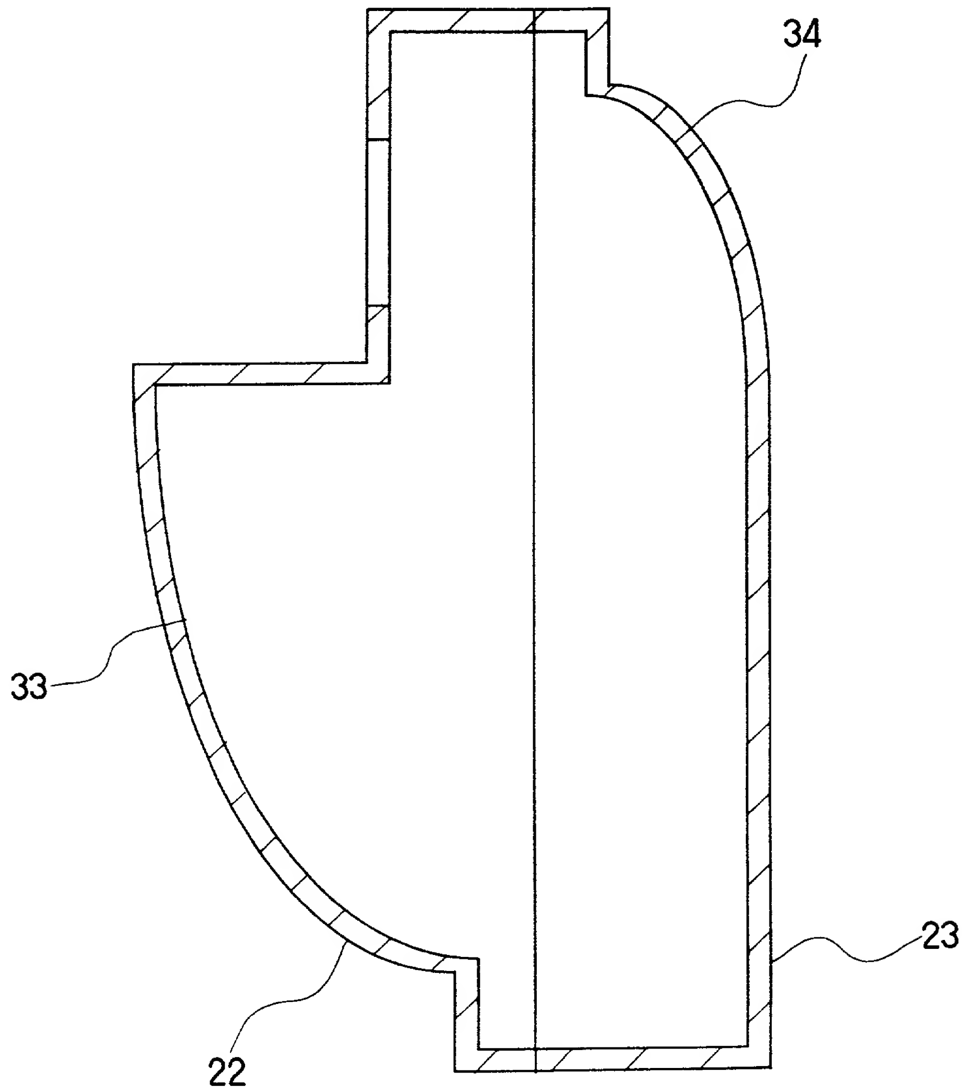

FIG. 25

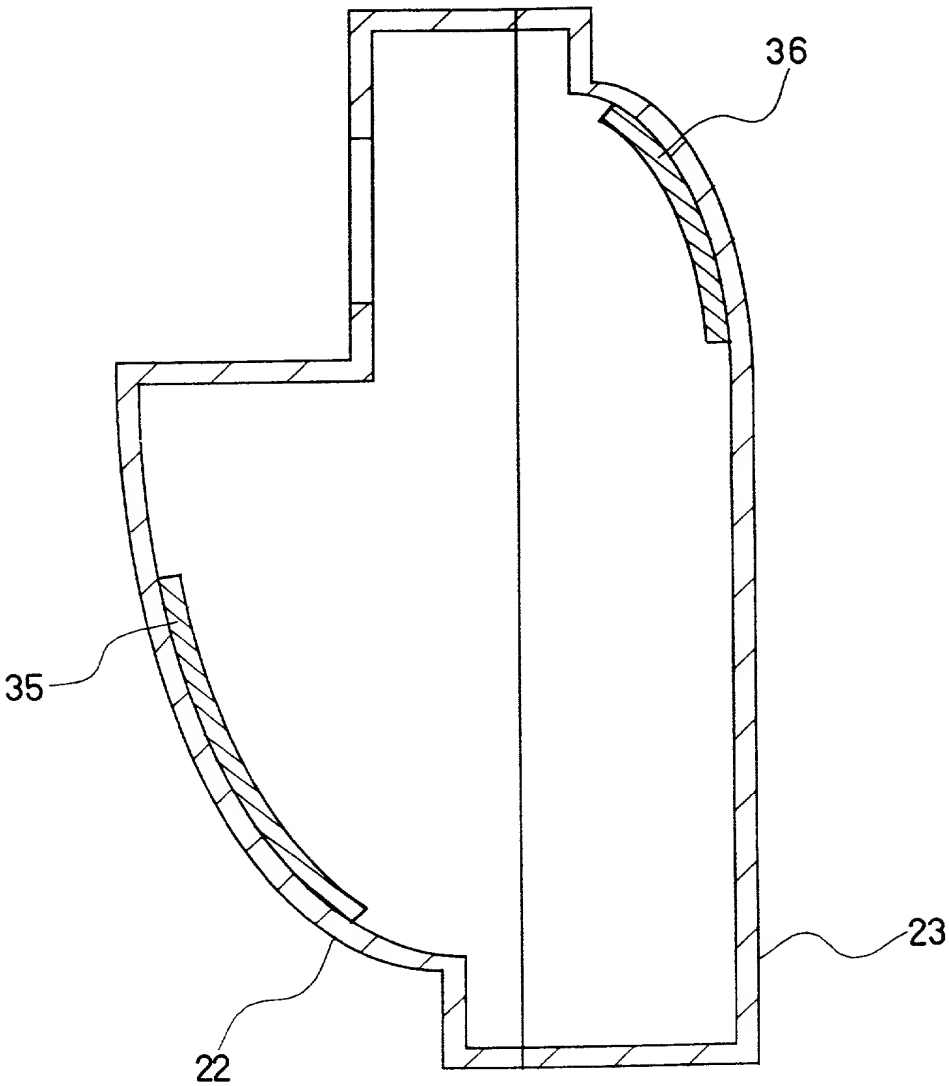

FIG. 26

09/913018

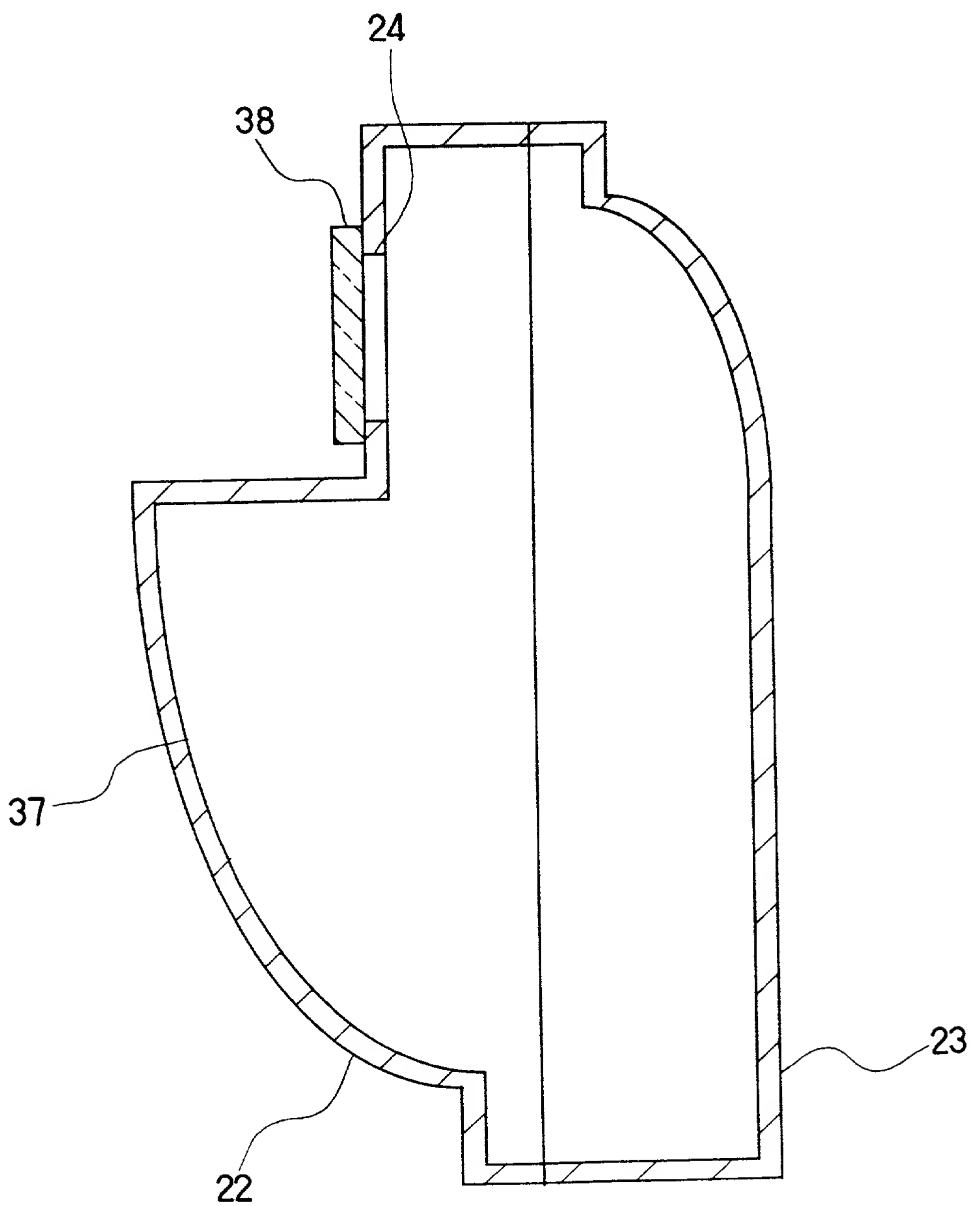

FIG. 27

09/913018

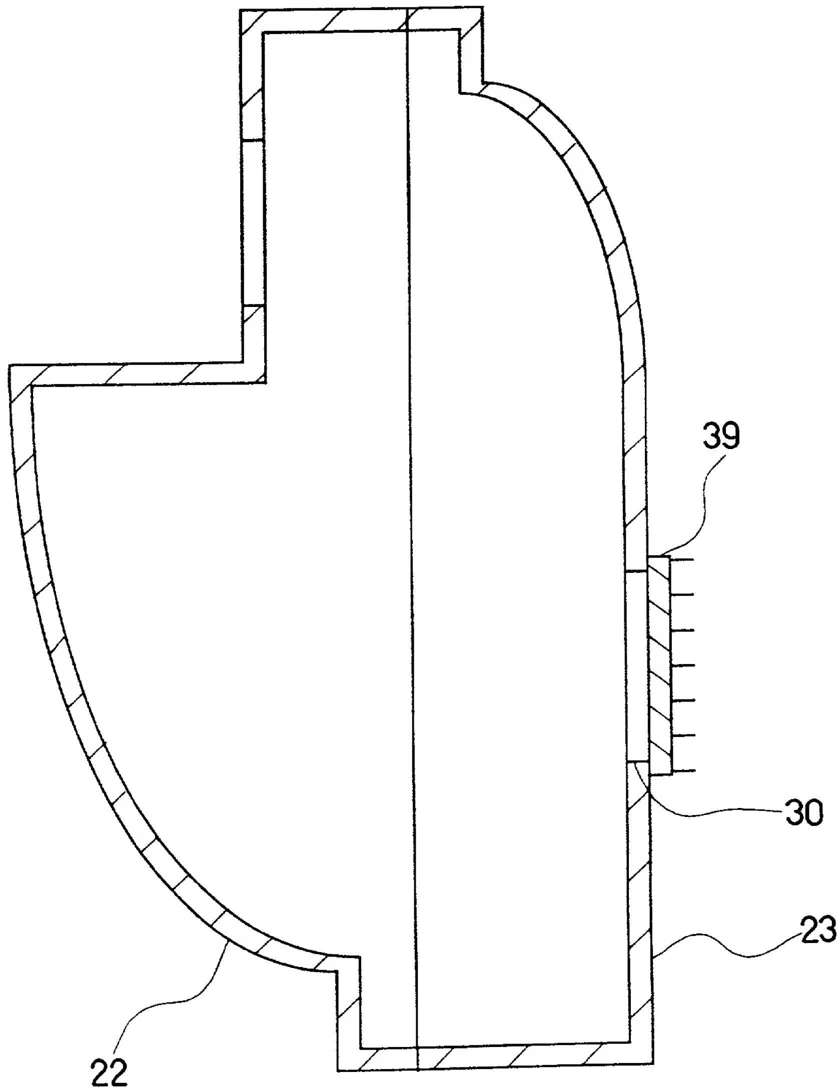

FIG. 28

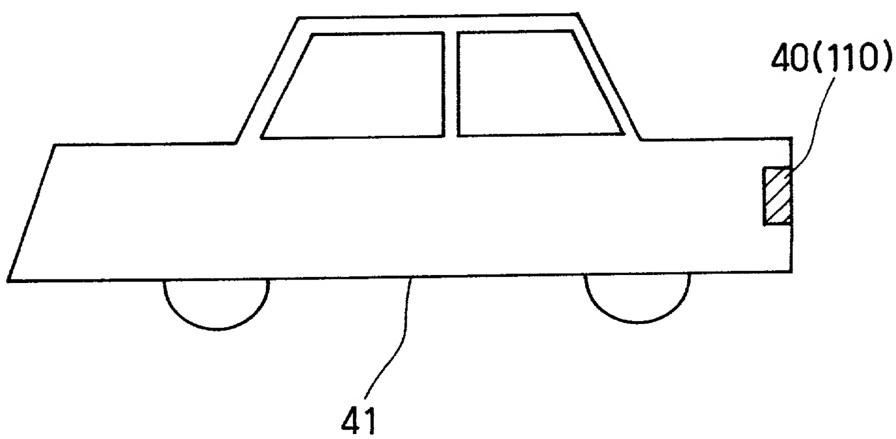

FIG. 29

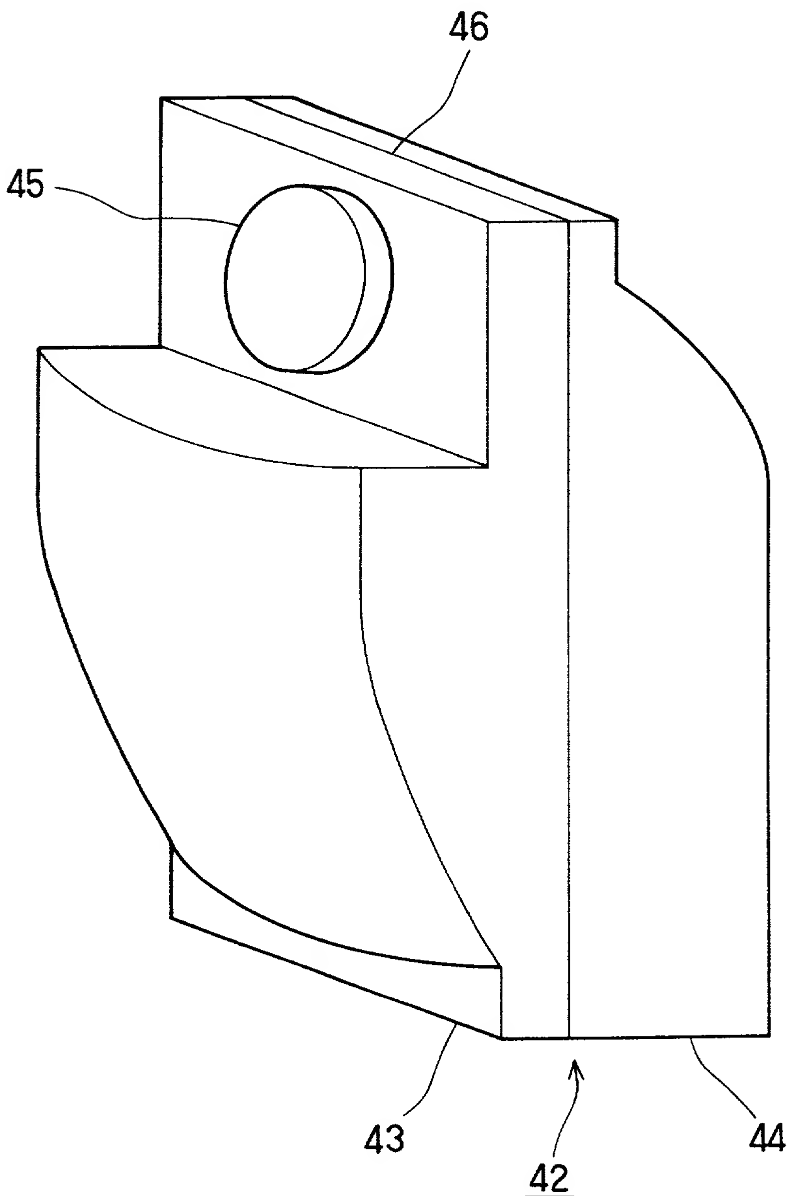

FIG. 30

09/913018

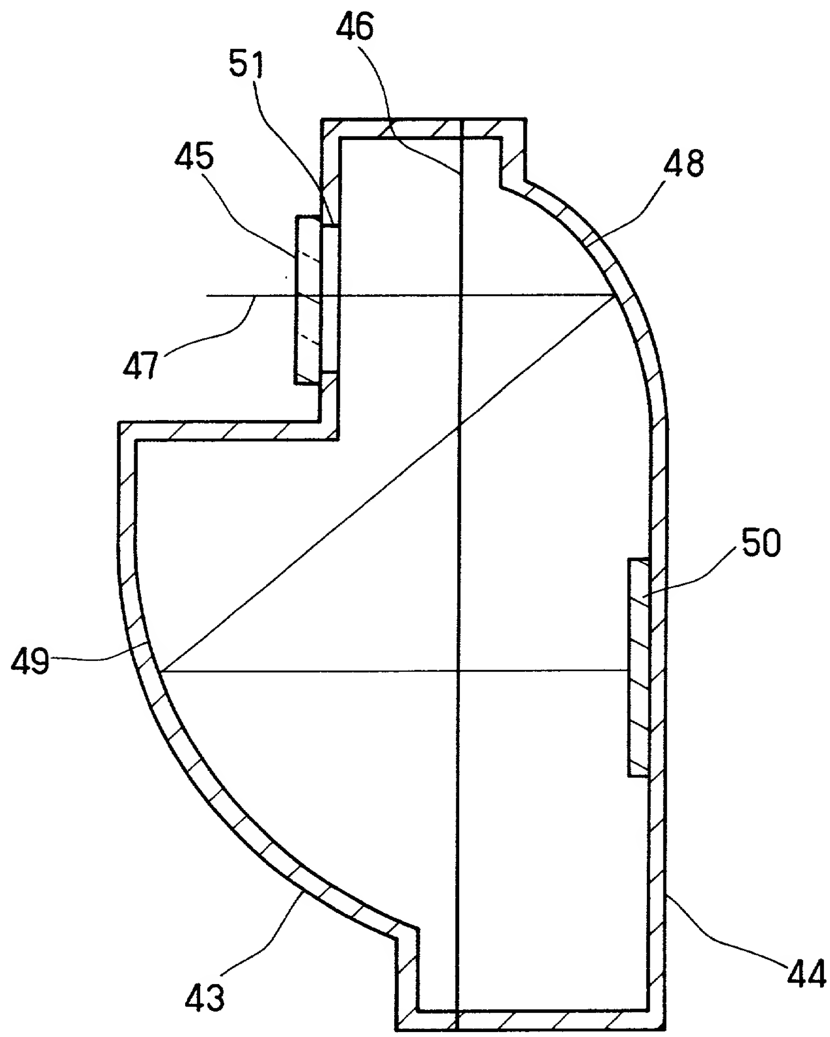

FIG. 31

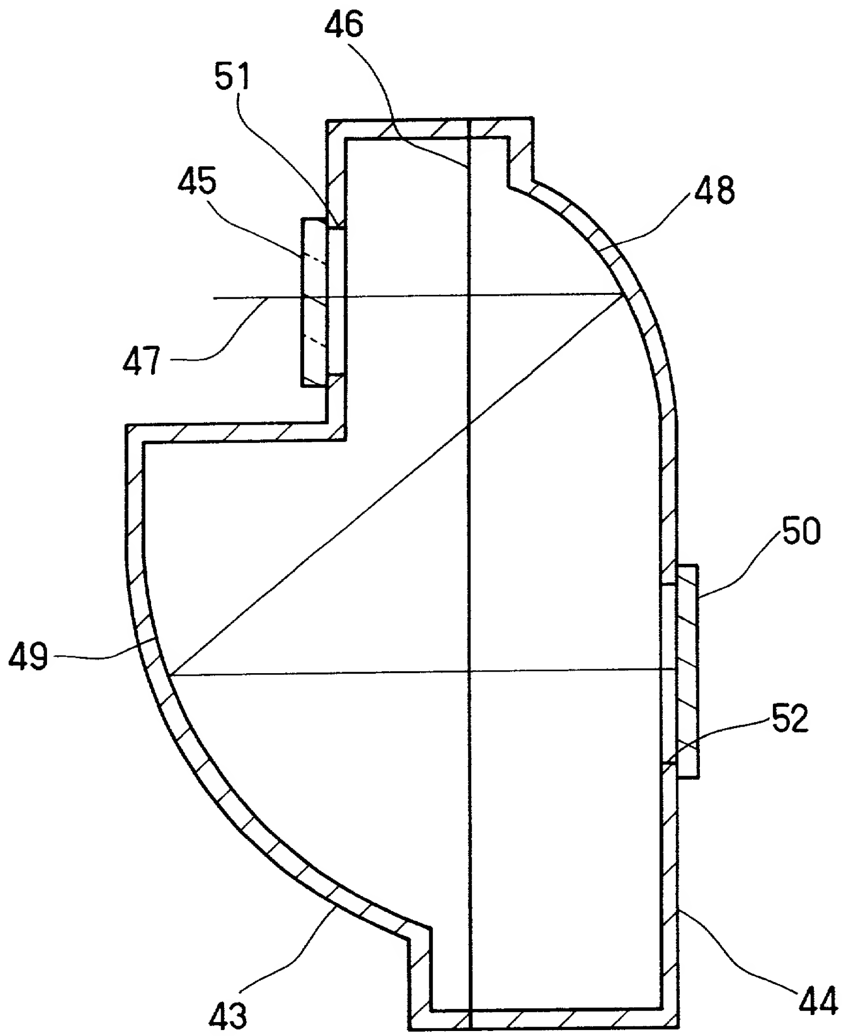

FIG . 32

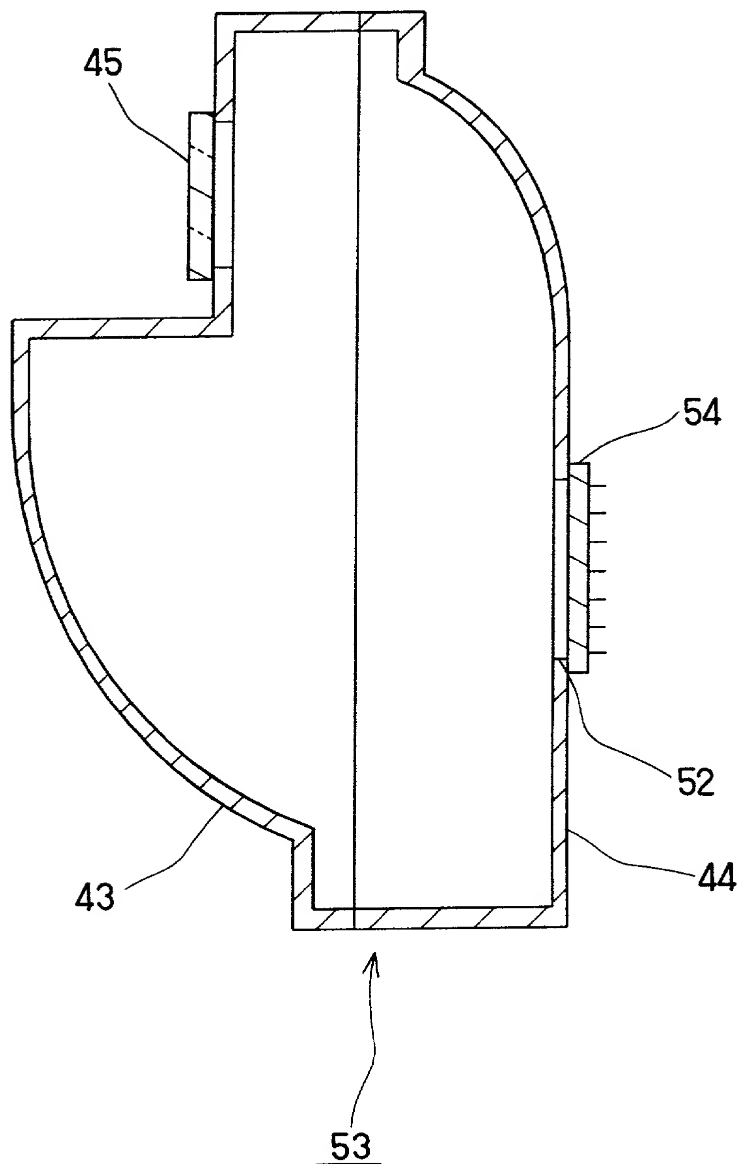

FIG. 33

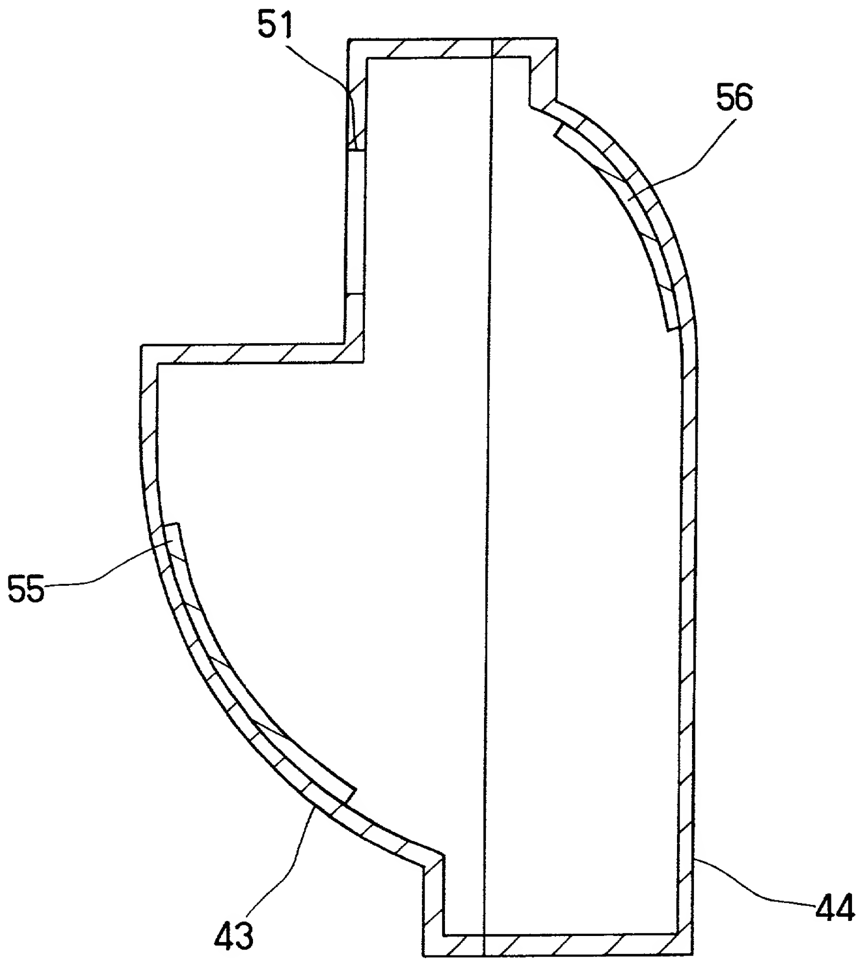

FIG. 34

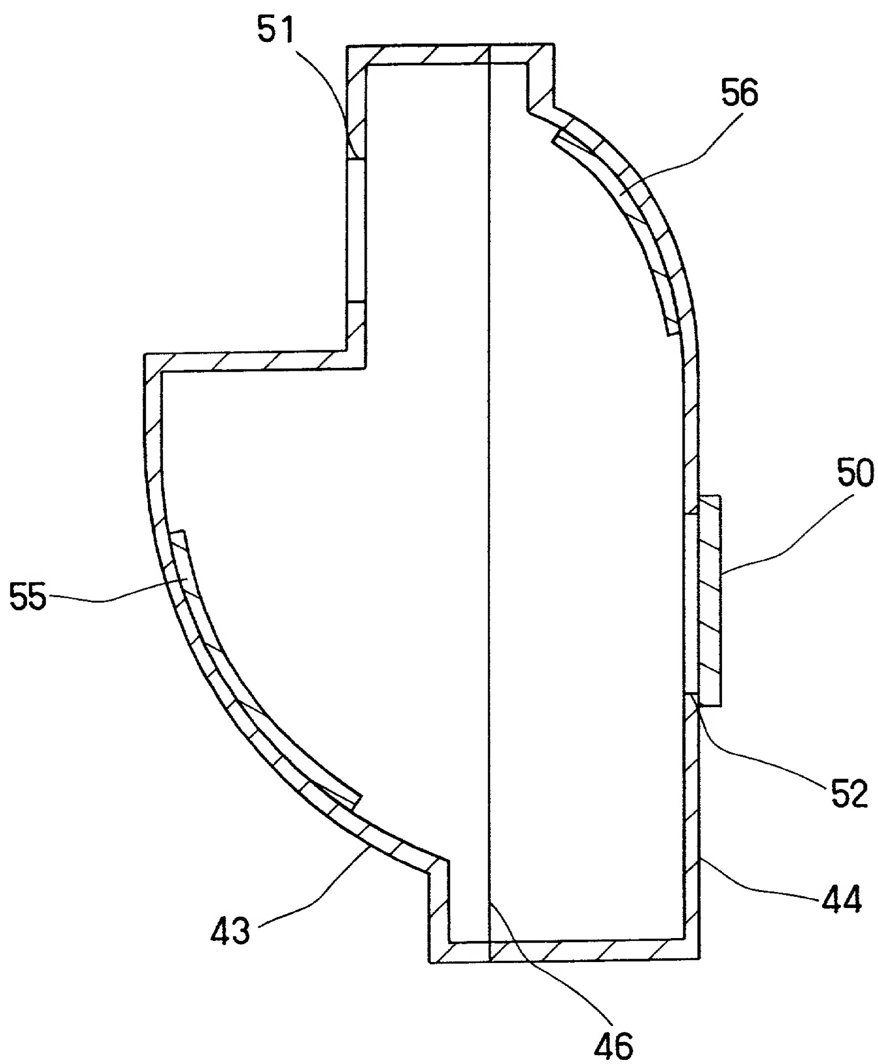

FIG. 35

09/913018

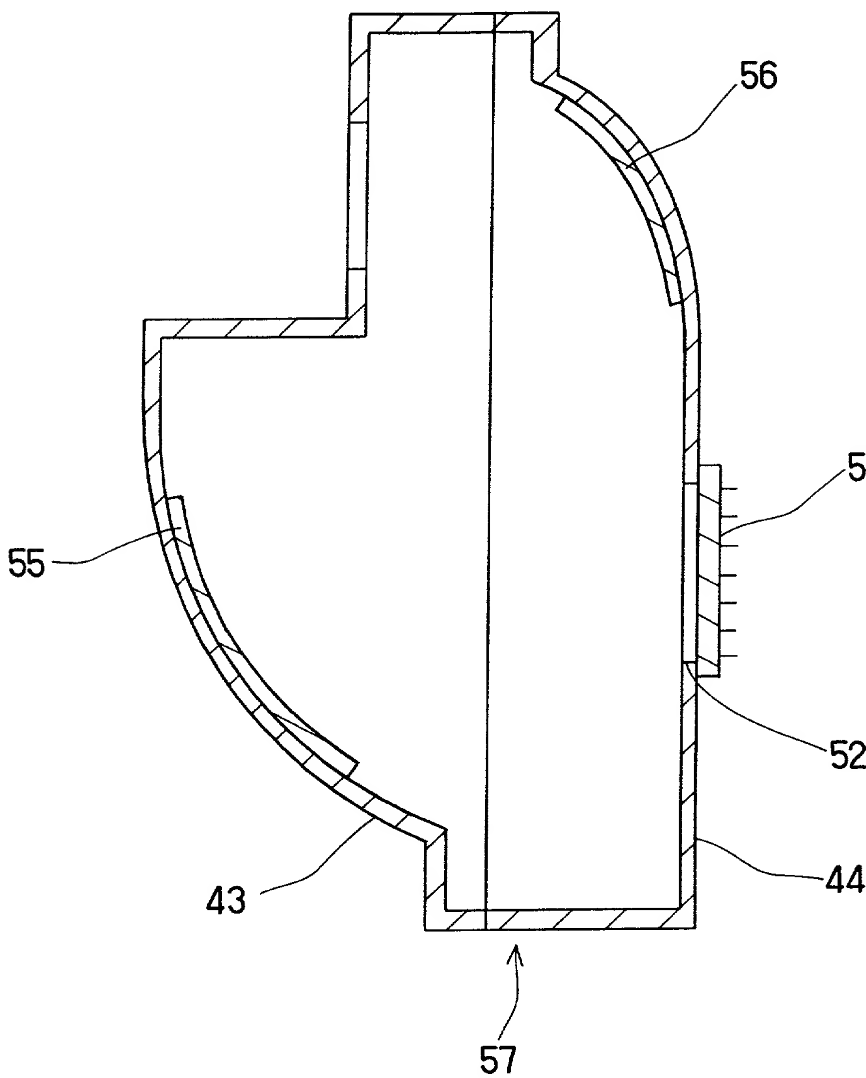

FIG. 36

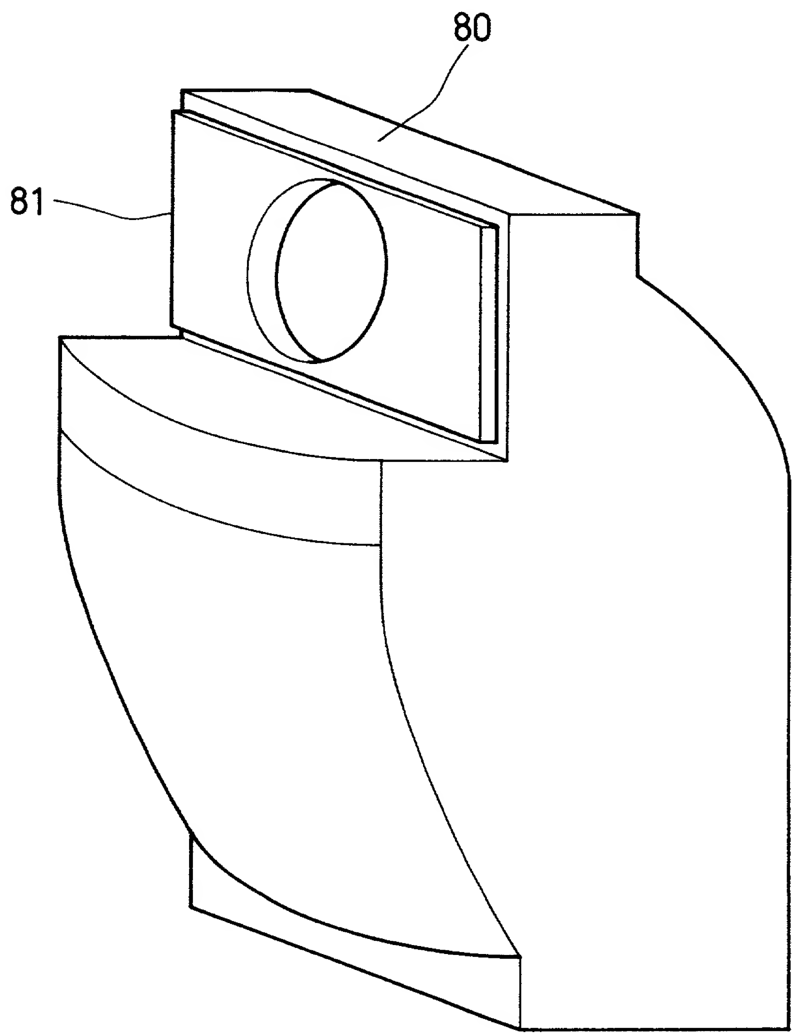

FIG. 37

09/913018

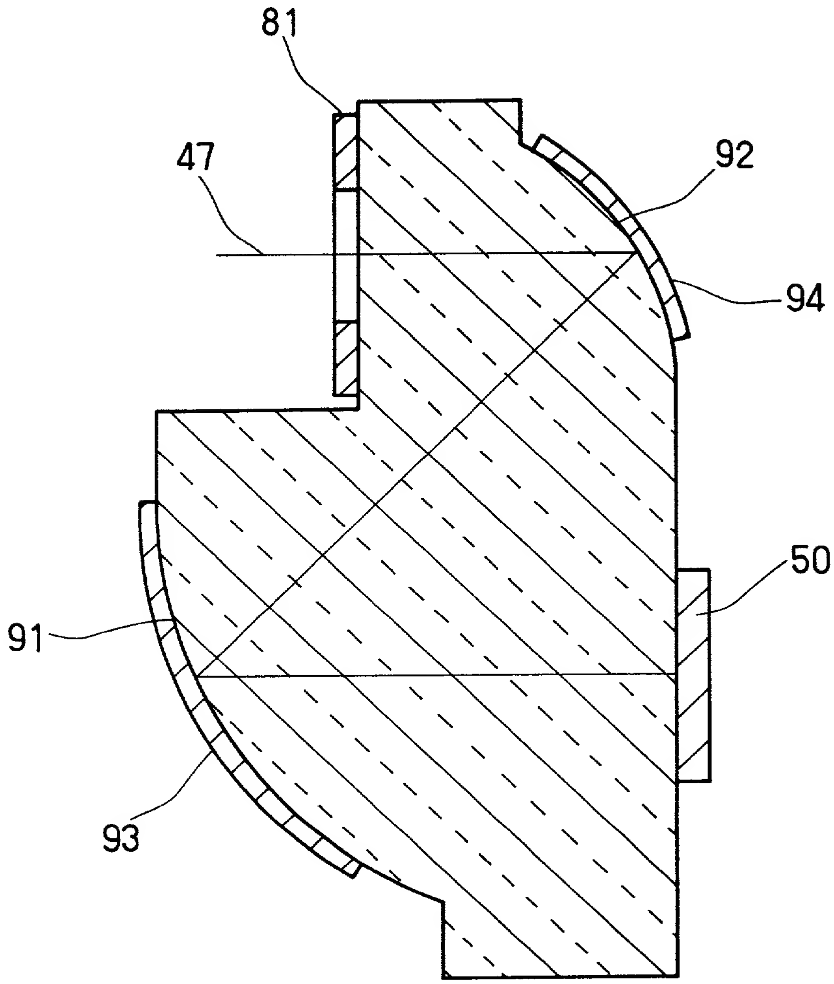

FIG. 38

09/913018

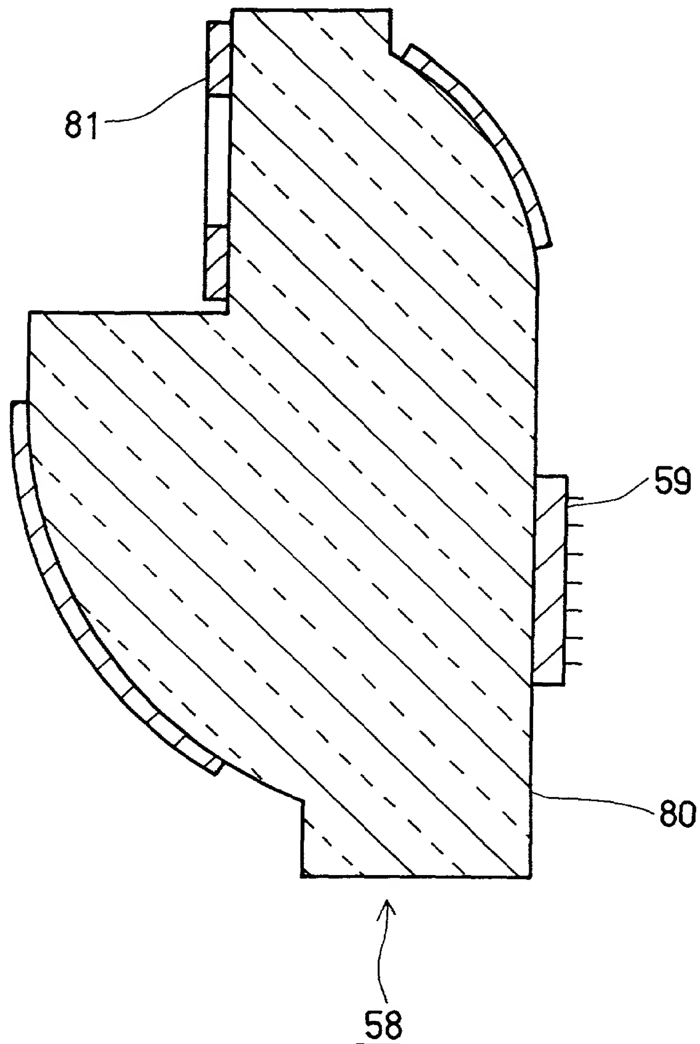

FIG . 39

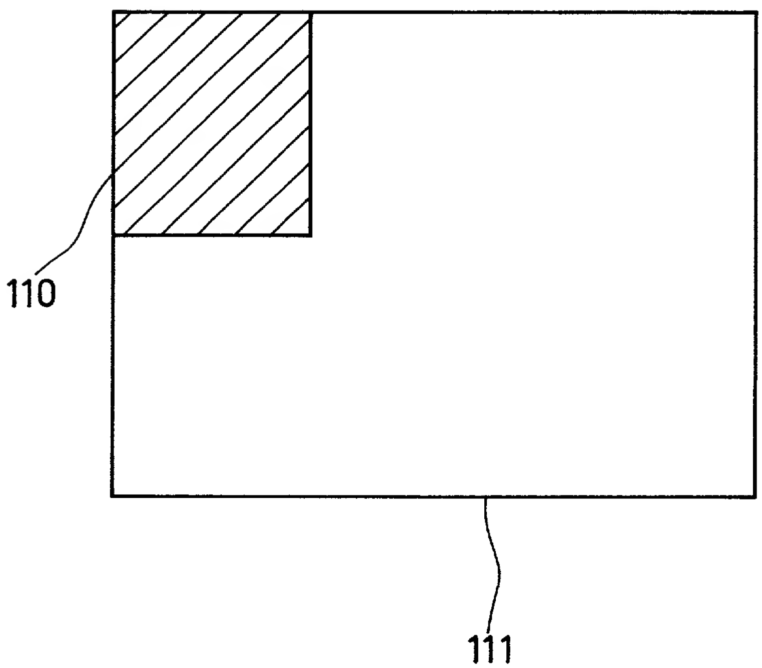

FIG. 40

MERCHANT & GOULD P.C.

United States Patent Application

COMBINED DECLARATION AND POWER OF ATTORNEY

As a below named inventor I hereby declare that: my residence, post office address and citizenship are as stated below next to my name; that

I verily believe I am the original, first and sole inventor (if only one name is listed below) or a joint inventor (if plural inventors are named below) of the subject matter which is claimed and for which a patent is sought on the invention entitled: REFLECTIVE OPTICAL DEVICE, AND REFLECTIVE SOLID-STATE OPTICAL DEVICE, AND IMAGING DEVICE, MULTI-WAVELENGTH IMAGING DEVICE, VIDEO CAMERA DEVICE, AND VEHICLE-MOUNTED MONITOR UTILIZING THE SAME

The specification of which
a. ☐ is attached hereto
b. ☒ was filed on ____________________ as application serial no. ________________ and was amended on
(if applicable) (in the case of a PCT-filed application) described and claimed in international no. PCT/JP00/00728 filed February 9, 2000 and as amended on September 4, 2000 and December 8, 2000, which I have reviewed and for which I solicit a United States patent.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, § 1.56 (attached hereto).

I hereby claim foreign priority benefits under Title 35, United States Code, § 119/365 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on the basis of which priority is claimed:

a. ☐ no such applications have been filed.
b. ☒ such applications have been filed as follows:

FOREIGN APPLICATION(S), IF ANY, CLAIMING PRIORITY UNDER 35 USC § 119			
COUNTRY	**APPLICATION NUMBER**	**DATE OF FILING (day, month, year)**	**DATE OF ISSUE (day, month, year)**
Japan	11-032881	10 February 1999	
Japan	11-128493	10 May 1999	
Japan	11-297123	19 October 1999	
ALL FOREIGN APPLICATION(S), IF ANY, FILED BEFORE THE PRIORITY APPLICATION(S)			
COUNTRY	**APPLICATION NUMBER**	**DATE OF FILING (day, month, year)**	**DATE OF ISSUE (day, month, year)**

I hereby claim the benefit under Title 35, United States Code, § 120/365 of any United States and PCT international application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. APPLICATION NUMBER	DATE OF FILING (day, month, year)	STATUS (patented, pending, abandoned)

I hereby claim the benefit under Title 35, United States Code § 119(e) of any United States provisional application(s) listed below:

U.S. PROVISIONAL APPLICATION NUMBER	DATE OF FILING (Day, Month, Year)

I hereby appoint the following attorney(s) and/or patent agent(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected herewith:

Albrecht, John W.	Reg. No. 40,481
Anderson, Gregg I.	Reg. No. 28,828
Ansems, Gregory M.	Reg. No. 42,264
Batzli, Brian H.	Reg. No. 32,960
Beard, John L.	Reg. No. 27,612
Black, Bruce E.	Reg. No. 41,622
Blasdell, Thomas L.	Reg. No. 31,329
Bogucki, Raymond A.	Reg. No. 17,426
Bruess, Steven C.	Reg. No. 34,130
Byrne, Linda M.	Reg. No. 32,404
Carlson, Alan G.	Reg. No. 25,959
Caspers, Philip P.	Reg. No. 33,227
Chiapetta, James R.	Reg. No. 39,634
Clifford, John A.	Reg. No. 30,247
Cochran, William W.	Reg. No. 26,652
Daignault, Ronald A.	Reg. No. 25,968
Daley, Dennis R.	Reg. No. 34,994
Dalglish, Leslie E.	Reg. No. 40,579
Daulton, Julie R.	Reg. No. 36,414
DeVries Smith, Katherine M.	Reg. No. 42,157
DiPietro, Mark J.	Reg. No. 28,707
Edell, Robert T.	Reg. No. 20,187
Epp Ryan, Sandra	Reg. No. 39,667
Funk, Steven R.	Reg. No. 37,830
Glance, Robert J.	Reg. No. 40,620
Golla, Charles E.	Reg. No. 26,896
Gorman, Alan G.	Reg. No. 38,472
Gould, John D.	Reg. No. 18,223
Gregson, Richard	Reg. No. 41,804
Gresens, John J.	Reg. No. 33,112
Hamre, Curtis B.	Reg. No. 29,165
Hillson, Randall A.	Reg. No. 31,838
Holzer, Jr., Richard J.	Reg. No. 42,668
Johnston, Scott W.	Reg. No. 39,721
Kadievitch, Natalie D.	Reg. No. 34,196
Kastelic, Joseph M.	Reg. No. 37,160
Kettelberger, Denise	Reg. No. 33,924
Knearl, Homer L.	Reg. No. 21,197
Kowalchyk, Alan W.	Reg. No. 31,535
Kowalchyk, Katherine M.	Reg. No. 36,848
Kubota, Glenn M.	Reg. No. 44,197
Lacy, Paul E.	Reg. No. 38,946
Larson, James A.	Reg. No. 40,443
Lasky, Michael B.	Reg. No. 29,555
Liepa, Mara E.	Reg. No. 40,066
Lindquist, Timothy A.	Reg. No. 40,701
Lynch, David W.	Reg. No. 36,204
Marschang, Diane L.	Reg. No. 35,600
McDaniel, Karen D.	Reg. No. 37,674
McDonald, Daniel W.	Reg. No. 32,044
McIntyre, Iain A.	Reg. No. 40,337
Mueller, Douglas P.	Reg. No. 30,300
Nelson, Albin J.	Reg. No. 28,650
Pauly, Daniel M.	Reg. No. 40,123
Phillips, John B.	Reg. No. 37,206
Plunkett, Theodore	Reg. No. 37,209
Pytel, Melissa J.	Reg. No. 41,512
Reich, John C.	Reg. No. 37,703
Reiland, Earl D.	Reg. No. 25,767
Rittmaster, Ted R.	Reg. No. 32,933
Schmaltz, David G.	Reg. No. 39,828
Schuman, Mark D.	Reg. No. 31,197
Schumann, Michael D.	Reg. No. 30,422
Scull, Timothy B.	Reg. No. 42,137
Sebald, Gregory A.	Reg. No. 33,280
Skoog, Mark T.	Reg. No. 40,178
Soderberg, Richard	Reg. No. P- 43,352
Sumner, John P.	Reg. No. 29,114
Sumners, John S.	Reg. No. 24,216
Tellekson, David K.	Reg. No. 32,314
Trembath, Jon R.	Reg. No. 38,344
Underhill, Albert L.	Reg. No. 27,403
Vandenburgh, J. Derek	Reg. No. 32,179
Vradenburgh, Anna M.	Reg. No. 39,868
Welter, Paul A.	Reg. No. 20,890
Wahl, John R.	Reg. No. 33,044
Whipps, Brian	Reg. No. 43,261
Wickhem, J. Scot	Reg. No. 41,376
Williams, Douglas J.	Reg. No. 27,054
Witt, Jonelle	Reg. No. 41,980
Wood, William J.	Reg. No. 42,236
Xu, Min S.	Reg. No. 39,536

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I hereby authorize them to act and rely on instructions from and communicate directly with the person/assignee/attorney/firm/ organization who/which first sends/sent this case to them and by whom/which I hereby declare that I have consented after full disclosure to be represented unless/until I instruct Merchant & Gould P.C. to the contrary.

Please direct all correspondence in this case to Merchant & Gould P.C. at the address indicated below:

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P.O. Box 2903
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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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§ 1.56 Duty to disclose information material to patentability.

(a) A patent by its very nature is affected with a public interest. The public interest is best served, and the most effective patent examination occurs when, at the time an application is being examined, the Office is aware of and evaluates the teachings of all information material to patentability. Each individual associated with the filing and prosecution of a patent application has a duty of candor and good faith in dealing with the Office, which includes a duty to disclose to the Office all information known to that individual to be material to patentability as defined in this section. The duty to disclose information exists with respect to each pending claim until the claim is canceled or withdrawn from consideration, or the application becomes abandoned. Information material to the patentability of a claim that is canceled or withdrawn from consideration need not be submitted if the information is not material to the patentability of any claim remaining under consideration in the application. There is no duty to submit information which is not material to the patentability of any existing claim. The duty to disclose all information known to be material to patentability is deemed to be satisfied if all information known to be material to patentability of any claim issued in a patent was cited by the Office or submitted to the Office in the manner prescribed by §§ 1.97(b)-(d) and 1.98. However, no patent will be granted on an application in connection with which fraud on the Office was practiced or attempted or the duty of disclosure was violated through bad faith or intentional misconduct. The Office encourages applicants to carefully examine:

(1) prior art cited in search reports of a foreign patent office in a counterpart application, and

(2) the closest information over which individuals associated with the filing or prosecution of a patent application believe any pending claim patentably defines, to make sure that any material information contained therein is disclosed to the Office.

(b) Under this section, information is material to patentability when it is not cumulative to information already of record or being made of record in the application, and

(1) It establishes, by itself or in combination with other information, a prima facie case of unpatentability of a claim;

or

(2) It refutes, or is inconsistent with, a position the applicant takes in:

(i) Opposing an argument of unpatentability relied on by the Office, or

(ii) Asserting an argument of patentability.

A prima facie case of unpatentability is established when the information compels a conclusion that a claim is unpatentable under the preponderance of evidence, burden-of-proof standard, giving each term in the claim its broadest reasonable construction consistent with the specification, and before any consideration is given to evidence which may be submitted in an attempt to establish a contrary conclusion of patentability.

(c) Individuals associated with the filing or prosecution of a patent application within the meaning of this section are:

(1) Each inventor named in the application:

(2) Each attorney or agent who prepares or prosecutes the application; and

(3) Every other person who is substantively involved in the preparation or prosecution of the application and who is associated with the inventor, with the assignee or with anyone to whom there is an obligation to assign the application.

(d) Individuals other than the attorney, agent or inventor may comply with this section by disclosing information to the attorney, agent, or inventor.